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GROUND BASED SIMULATION EVALUATION OF THE EFFECTS OF TIME DELAYS AND MOTION ON ROTORCRAFT HANDLING QUALITIES

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FOREWORD

The authors wish to acknowledge the contributions of several individuals at both STI and Ames. First, our appreciation goes to the evaluation pilots for their diligence in evaluations, comments, and suggestions throughout the simulation. The test pilots were Messrs. Munro Dearing, Rickey Simmons, and George Tucker of NASA-Ames (Rickey Simmons was a US Army test pilot who was assigned to the Aeroflightdynamics Directorate at the time of the simulation); Freddie Mills and Gary McVaney, with the US Army Airworthiness Qualification Test Directorate at Edwards Air Force Base, Edwards, CA; Mr. Ron Gerdes a retired NASA pilot now employed by SYRE at Ames; and Mr. Roger Hoh of Hoh Aeronautics Inc. We also wish to thank the NASA engineers, especially Messrs.. Richard McFarland and Robert Gardner, for their expert assistance through the simulation; and the SYRE programmers and operators, Messrs.. Bob Morrison and Alan Lee. At STI, Messrs.. Bimal Aponso and David Klyde provided help with the data analysis , and Mr. Charles Reaber and Ms. Donna Taylor prepared the final report. Finally, our sincere appreciation goes to Mr. Richard Bray, recently retired from NASA-Ames, who volunteered several of his evenings to assist in the tune-up of the motion system washouts and gains.

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SECTION I

INTRODUCTION

A. BACKGROUND

Ground-based simulation is an important tool in the assessment of handling qualities of rotorcraft for both research and development. The strengths and limitations of the simulation facilities are well known and recognized in the rotorcraft community. What is not as well documented, however, is the relative impact of various elements in the simulator itself on perceived handling qualities. For example, past studies have demonstrated that rate-augmented vehicles that exhibit good handling qualities in flight are much more difficult to control on ground-based simulators (Ref. 1).

Besides the obvious issues of simulation fidelity and flight/simulation transference (e.g., Ref. 2), there are other fundamental issues in simulation design that also impact the use of ground-based simulators for handling qualities research. All of these issues, such as inherent time delays and their compensation (e.g., Refs. 3 and 4), simulator sickness (e.g., Ref. 5), and the requirements on motion (e.g., Refs. 6, 7, 8, and 9), have been investigated in great detail in terms of their impact on human operator response dynamics and assessments of fidelity. Few studies, however, have explored the specific impact of these issues on handling qualities evaluations.

A study was conducted on the NASA Ames Research Center's Vertical Motion Simulator (VMS) to evaluate the effects of simulator characteristics on handling qualities. The primary focus of the simulation was on piloted assessment of the variations — i.e., Handling Qualities Ratings (HQRs) and comments. Seven pilots from the Army, NASA, and private industry participated in the simulation. Most evaluations were conducted with a baseline set of rotorcraft dynamics, using a simple transfer-function model of an uncoupled helicopter with Level 1 handling qualities based on ADS-33C (Ref. 10). The pilots were instructed to evaluate each configuration as if it were a new aircraft; therefore, differences in HQRs as visual and motion parameters are changed were due entirely to the pilots' perceptions of handling qualities, rather than to changes in the aircraft model itself. Seven precision and aggressive low-speed maneuvers from ADS-33C were used as the evaluation tasks.

B. OBJECTIVES

Effects of variations in the three major elements of the simulation — the motion system, visual system, and math model — were evaluated. Specific variations and the philosophies behind them were as follows.

Motion system: The effects of motion were evaluated by performing a portion of the experiment fixed-base and repeating this portion moving-base. The VMS employs linear motion washouts with second-order filters; the baseline set of washouts used in the moving-base evaluations were developed for this experiment based on a combination of past experience and the involvement of NASA engineers. This baseline set of washouts followed the NASA philosophy of transmitting initial accelerations at the expense of motion/visual/model phasing. A third set of modified washouts was developed during the simulation that reduced the phase distortions between the motion and visual responses, but at the expense of amplitude of onset accelerations. Supporting information on the design of motion systems in general, and the selection of the washout parameters for this simulation in particular, is given in Appendix A.

Visual system delays: A compensation filter is employed on simulations at Ames to effectively remove the delay-inducing effects of pipeline delays in the visual image generation system (Ref. 3). While this filter greatly reduces the overall visual delays, it increases the mismatch in phasing between the visual and motion responses. Past studies on such visual/motion mismatch (described in Appendix A) have had conflicting results: it is unclear whether it is better to compensate the visual response fully, thus increasing the mismatch, or to minimize the phase mismatch at the expense of delayed visual response. Effects of adding and removing the visual delay compensation were evaluated and compared to adding an equivalent pure time delay in the overall simulation.

Bandwidth/Response-Type/delay tradeoffs: Combined effects of variations in response dynamics with varying amounts of visual or total time delays were investigated. Two Rate Response-Types (Ref. 10) and one Attitude Command/Attitude Hold Response-Type were evaluated, though most runs were made with the baseline Rate system that provided Level 1 handling qualities by the requirements of ADS-33C. Incremental time delays, in the form of both pure delay in the model and combinations of model-plus-visual delay (the latter by turning the compensation filter on and off), were simulated, from 0 to 383 msec.

Because of the key variation parameters, it was essential that a thorough accounting of the characteristics of all elements of the simulation be made. To this end, this experiment included a full documentation of the dynamics of the math model, visual, and cab dynamics. A procedure was developed by NASA to provide online capability for frequency-response identification of the dynamics. Using this procedure it was possible to change any of the math model, visual, or motion variables and immediately assess the impact of these changes on the simulation setup. Additional post-simulation documentation was performed using piloted frequency sweeps.

C. NATURE OF THIS STUDY

This study amounted to a preliminary assessment of the interplay among the key elements of the piloted simulation. A considerable portion of the simulation time was devoted exclusively to verifying the dynamics of the VMS prior to piloted evaluation; actual evaluation time was, therefore, somewhat limited, and the results should be viewed as guides for future work as opposed to final conclusions. For example, there was no attempt to search for an "optimum" set of motion washouts and response gains for the tasks performed, but instead a first cut was made at one possible alternative set. A much more thorough sweep of motion dynamics, following the first cut taken here, is justified.

D. ORGANIZATION OF THE REPORT

Section II of this report describes the experiment design, with further documentation provided by Appendices A, B, and C. Section III analyzes the handling qualities ratings obtained; actual ratings and transcribed pilot comments are given in Appendices D and E, respectively. Section IV presents the conclusions based on the analysis of Section III. Included in Section IV are recommendations of areas worthy of further investigation in follow-on simulation studies.

SECTION II

EXPERIMENT DESIGN

A. FACILITY

The simulation was conducted on NASA Ames Research Center's six-degree-of-freedom Vertical Motion Simulator (VMS) with the Rotorcraft Simulator Motion Generator (RSMG) system, depicted in Fig. 1. The simulator cab was mounted such that the greatest translational travel was in the lateral direction. Translational motion is limited by hard stops at ±30 ft vertically, ±20 ft laterally, and ±4 ft longitudinally. Software trips in the motion system further limited the actual available range of linear travel from center position to ±25 ft vertically, ±18 ft laterally, and ±2.5 ft longitudinally.

The cockpit was representative of a single-pilot helicopter configuration with three horizon-level monitors for the out-the-window view; the rightmost window included a view of the ground environment near the helicopter as well. Visual display generation was via a Digital Image Generator (DIG). Conventional cockpit head-down instruments were used, with the addition of a digital altimeter. No head-up displays were used.

Cockpit controls were conventional, with a center-mounted cyclic, left-hand collective, and pedals. A sidestick capable of two-, three-, or four-axis control was also mounted in the cockpit but was not used for this simulation. Variable-feel McFadden control loaders were used on all controls; force-feel characteristics were fixed throughout the simulation at the values listed in Table 1. The

TABLE 1. COCKPIT CONTROLLER CHARACTERISTICS

PARAMETER	LONG. CYCLIC	LAT. CYCLIC	PEDALS	COLLECTIVE
Travel (in.)	±5	±5	±3	±5
Breakout (lbs)	0.5	0.5	4	0
Friction (lbs)	0.5	0.5	3	2
Gradient (lb/in.)	1.0	1.0	10	0

VMS NOMINAL OPERATIONAL MOTION LIMITS			
AXIS	DISPL	VELOCITY	ACCEL
VERTICAL	±30	16	24
LATERAL	±20	8	16
LONGITUDINAL	±4	4	10
ROLL	±18	40	115
PITCH	±18	40	115
YAW	±24	46	115
ALL NUMBERS, UNITS ft, deg, sec			

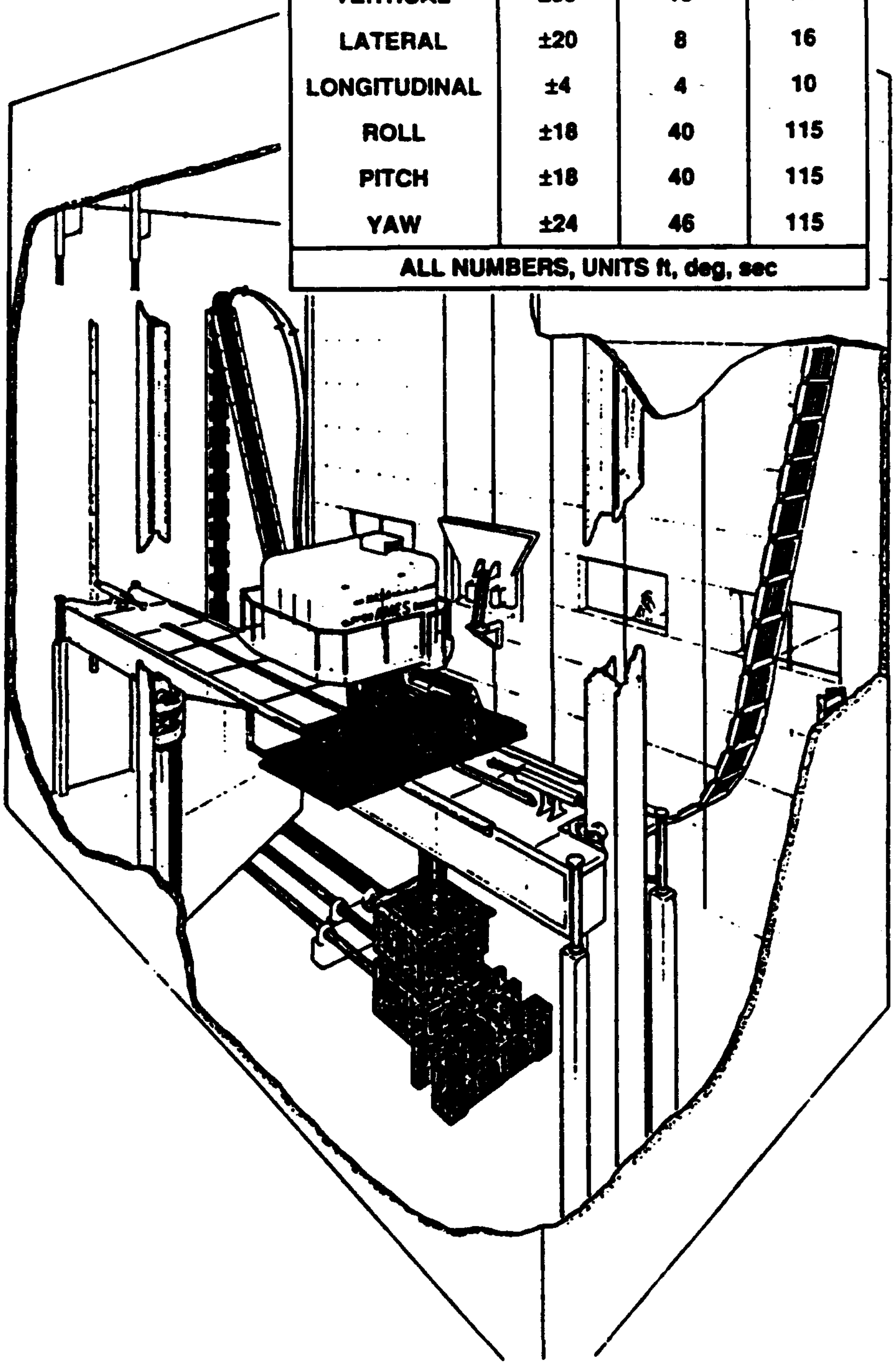


Figure 1. Vertical Motion Simulator

command signals were displacement for all controllers. Cyclic stick characteristics were symmetric for pitch and roll. Force/deflection dynamics of the cyclic were not measured in the simulation, but were estimated based on pot settings to be approximately

$$\frac{F_s}{\delta_s} = \frac{11.4^2}{s^2 + 2(0.3)(11.4)s + 11.4^2} \left[\frac{\text{lb}}{\text{in.}}\right]$$

in both pitch and roll.

Figure 2 is a schematic of the simulation layout. Cockpit control deflections, $\delta(s)$, are sampled by an analog-to-digital (A/D) converter and sent via digital-to-digital (D/D) interface to the host computer (point A on Fig. 2). The host computer for the simulation model was a CDC 7600 operating at a cycle rate, T, of 50 samples per second (20 msec frame time). Model accelerations, $\dot{w}(z)$, are computed at every sample (point B). The model accelerations are used by the motion-drive software to compute motion drive command signals, $w_d(z)$ (point C). These signals are sent via D/D and D/A to the cab motion system. Sampling of the responses of the VMS motion system accelerations, $w_m(s)$, and rates, $v_m(s)$, requires an additional A/D and D/D interface (point D). Cab accelerations and rates were measured in this simulation using both standard instrumentation and an add-on package of accelerometers and rate gyros. This is discussed further below and in Appendix B.

Model rates, u(z), are computed from the model accelerations with an advancing-integration algorithm that effectively provides a one-cycle lead (point F on Fig. 2). Model positions, u(z), are then integrated from the rates (point G) to compute the computer-generated imagery (CGI) commands for the Digital Image Generator (DIG). A visual delay compensation algorithm (Refs. 3, 4, and 12) provides lead adjustment to offset these transport delays, and evaluations were made with this compensation algorithm both on and off (as is discussed in more detail below). The CGI position commands, $u_c(z)$ (point H in Fig. 2), are transmitted via a D/D interface to the cockpit visual display. The DIG computer operated at 30 samples per second (33.3 msec frame time). The DIG computer uses a pipeline that requires a total of 2-1/2 computer cycles to generate an image and fill half of the monitors in the cockpit, resulting in an effective time delay of (2.5)*(33.3) = 83.3 msec (Ref. 3). Since this pipeline delay was known, no attempt was made to measure the actual cockpit visual display response.

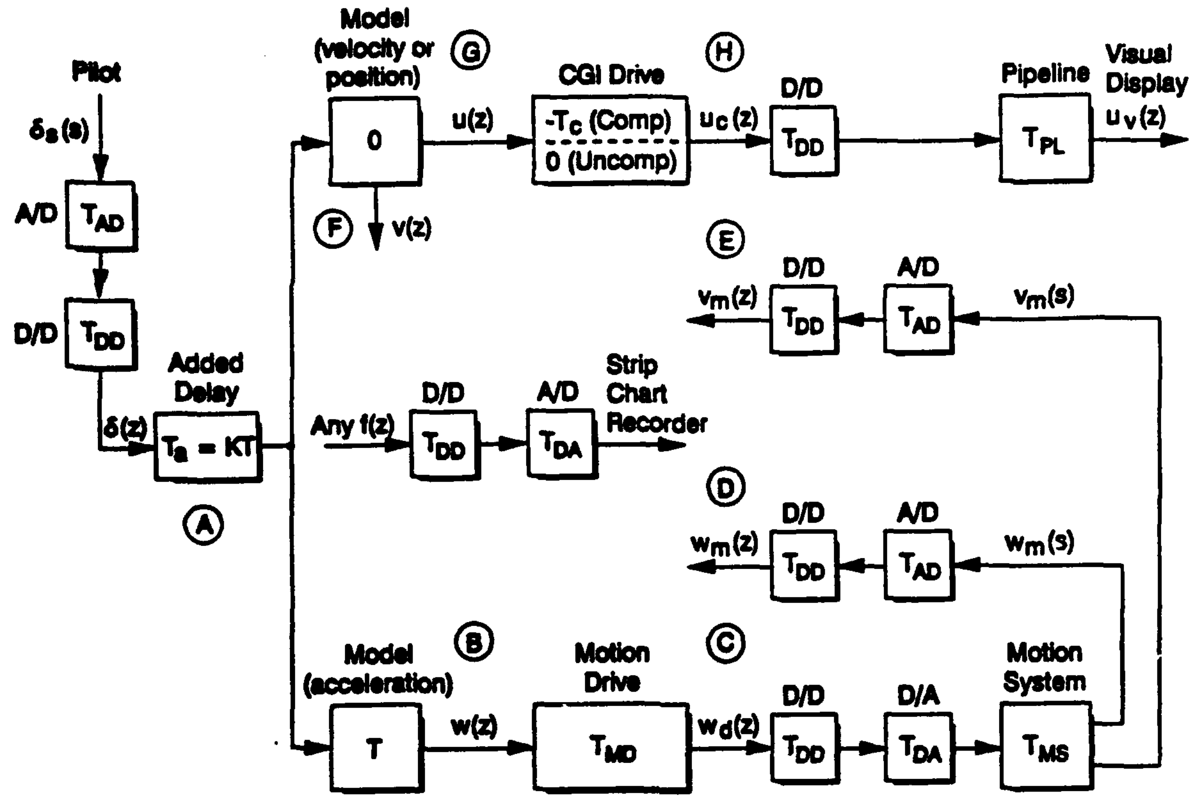


Figure 2. Delay Sources in the VMS Simulation Facility

B. MATH MODEL

The mathematical model for the rotorcraft was a generic, uncoupled stability-derivative model that has been used for several simulations at Ames (e.g., Refs. 13 and 14). Changes in dynamic response characteristics are effected by altering the basic aircraft stability and control derivatives; for example, the transfer function for pitch attitude response to longitudinal cyclic was represented by

$$\frac{\theta}{\delta_e} = \frac{M_{\delta_e}}{s^2 - M_q s - M_\theta}$$

For nonzero M_θ, the Response-Type is Attitude Command/Attitude Hold with $M_\theta = \omega^2_n$ and $M_q = 2\zeta\omega_n$; setting $M_\theta = 0$ produces a Rate Response-Type. Control sensitivity in both cases is varied by changing M_{δ_e}. Variations in Response-Type and Bandwidth were achieved by varying M_q and M_θ, while M_{δ_e} was fixed for each configuration to provide Level 1 control power as specified by ADS-33C (Ref. 10). Values of the derivatives for the three pitch and roll Response-Types are listed in Table 2.

Heave and yaw dynamics were fixed throughout the simulation at values that exceeded the Level 1 requirements of ADS-33C.

TABLE 2. DERIVATIVE VARIATIONS FOR TEST CASES

DERIVATIVE (UNITS)	RESPONSE-TYPE (PITCH AND ROLL)		
	Low-Bandwidth Rate	High-Bandwidth Rate	ACAH
M_{δ_e} (rad/sec²/in.)	0.5425	1.4	1.0
M_q (rad/sec)	-1.55	-4.0	-2.94
M_θ (rad/sec²)	0	0	-4.41
L_{δ_a} (rad/sec²/in.)	0.92	1.4	1.0
L_p (rad/sec)	-2.63	-4.0	-2.94
L_ϕ (rad/sec²)	0	0	-4.41

NOTE: $\frac{\theta}{\delta_e} = \frac{M_{\delta_e}}{s^2 - M_q s - M_\theta}$; $\frac{\phi}{\delta_a} = \frac{L_{\delta_a}}{s^2 - L_p s - L_\phi}$

C. MOTION SYSTEM VARIATIONS

Even though the VMS provides a large range of linear and angular travels, there are still very tight limitations on maneuvering space that necessitate lowered response gains and high washout break frequencies (e.g., Ref. 9). The selection of such gains and washouts is a compromise between the desire for realism in motion and the realities of space limitations. Ideally, the values selected reflect the requirements of the particular maneuvers to be flown and the expectations of the pilot (as discussed in detail in Appendix A).

The motion system of the VMS uses linear washouts with second-order filter characteristics (Ref. 9). Variables available for fine-tuning consist of the overall motion gain (which determines the scale-down from the real world — e.g., a gain of 0.7 means 70% of full-scale acceleration) and damping and natural frequency of the washout filter (which determines the rate at which the "correct" response is removed and the simulator cab returned to center position).

Prior to the start of formal evaluations, a set of motion gains and washout frequencies was developed by NASA personnel for the evaluation tasks of this simulation. The initial motion gains and washouts were developed under the guidance of Mr. Richard Bray, who had recently retired from NASA but volunteered to assist in setting up the motion dynamics. The motion gains and washouts, referred to in this report as Baseline motion, incorporated relatively large initial responses (on the

order of 30% to 60% of full scale), with correspondingly large washouts (break frequencies of 0.2 to 0.7 rad/sec). This resulted in a simulator command that transmitted much of the initial acceleration to the pilot, but that very quickly washed out the rates and translations. As is shown in Appendix A, the break frequencies of these washout filters produce significant phase distortion around the frequencies for piloted control, e.g., 0.5-5 rad/sec.

A variation to the baseline set of gains and washouts was devised that reduced the phase distortions at the frequencies for piloted control. Emphasis was placed on reducing the phase error between simulated motion and actual motion to less than 30 deg over the frequencies from 1 to 5 rad/sec (Appendix A). This involved lower washout break frequencies in the pitch, roll, and vertical axes, which necessitated the use of lower gains as well. Development of this Modified motion set was iterative, with repeated applications of an on-line frequency-response program (RSVP, described in Appendix B) and piloted evaluations. This was intended to be an exploratory study only, in preparation for a more formal and systematic variation in motion response characteristics. As such, the modified motion set was not necessarily optimized for the tasks flown in this simulation. Given further development time, similar modifications to the motion gains and washouts would have been made for the other axes of response.

Table 3 lists the washout filters for the Baseline and Modified motion systems. The modified roll and heave filters have lowered gains and greatly reduced washout break frequencies; yaw dynamics were not changed, and the differences in pitch were due to fine-tuning of the baseline motion system following the software changes mentioned above. The gain reduction in sway was made to retain proper roll-sway coordination. The motion drives on the VMS include provisions for increasing the washouts as airspeed increases. This is necessary to provide protection against large linear accelerations that are possible at high speeds (due to velocity-dependent components of acceleration). Between the low- and high-speed values the gains and break frequencies of the washout filters were computed by linear interpolation. Five of the seven tasks evaluated in the simulation (see Appendix C for a description of the tasks) were performed at hover or very low airspeeds. Only the slalom and dash/quickstop involved operations at airspeeds above 20 to 30 kt, so the emphasis on the development of washouts was naturally placed on the low-speed sets. As a result, discussion of the washout filter characteristics in this report focuses only on the low-speed sets.

Frequency-response comparisons of the washout filters, as well as a comparison of their gain attenuation and phase distortion characteristics, are presented in Appendix A.

A simple illustrative example of the effects of the two sets of motion washouts is shown in Fig. 3. The time responses in this figure are for a simple first-order representation of the helicopter in heave, with no additional time delays, lags, etc. A double-pulse collective input was applied to this

TABLE 3. MOTION WASHOUT FILTERS

	Baseline Set		Modified Set	
Axis	V ≤ 30 kt	V ≥ 60 kt	V ≤ 20 kt	V ≥ 50 kt
Roll	$\frac{0.3(0)^2}{[0.707, 0.7]}$	$\frac{0.25(0)^2}{[0.707, 0.85]}$	$\frac{0.15(0)^2}{[0.707, 0.3]}$	$\frac{0.10(0)^2}{[0.707, 0.4]}$
Pitch	$\frac{0.5(0)^2}{[2.0, 0.2]} = \frac{0.5(0)^2}{(0.054)(0.746)}$	Same	$\frac{0.25(0)^2}{[0.707, 0.3]}$	Same
Yaw	$\frac{0.3(0)^2}{[2.5, 0.2]} = \frac{0.3(0)^2}{(0.042)(0.958)}$	Same	Same as Baseline	Same as Baseline
Surge	0	0	0	0
Sway	$\frac{0.8(0)^2}{[0.707, 0.6]}$	$\frac{0.6(0)^2}{[0.707, 0.6]}$	$\frac{0.6(0)^2}{[0.707, 0.6]}$	Same
Heave	$\frac{0.6(0)^2}{[0.707, 0.3]}$	$\frac{0.5(0)^2}{[0.707, 1.2]}$	$\frac{0.4(0)^2}{[0.707, 0.05]}$	$\frac{0.3(0)^2}{[0.707, 0.5]}$

Notes: a) Shorthand Notation is $(a) \equiv (s + a)$; $[\zeta, \omega_n] \equiv [s^2 + 2\zeta\omega_n s + \omega_n^2]$

b) Filters are for $\frac{\text{simulator acceleration}}{\text{aircraft acceleration}}$

c) Filter parameters vary linearly with airspeed between low and high speeds

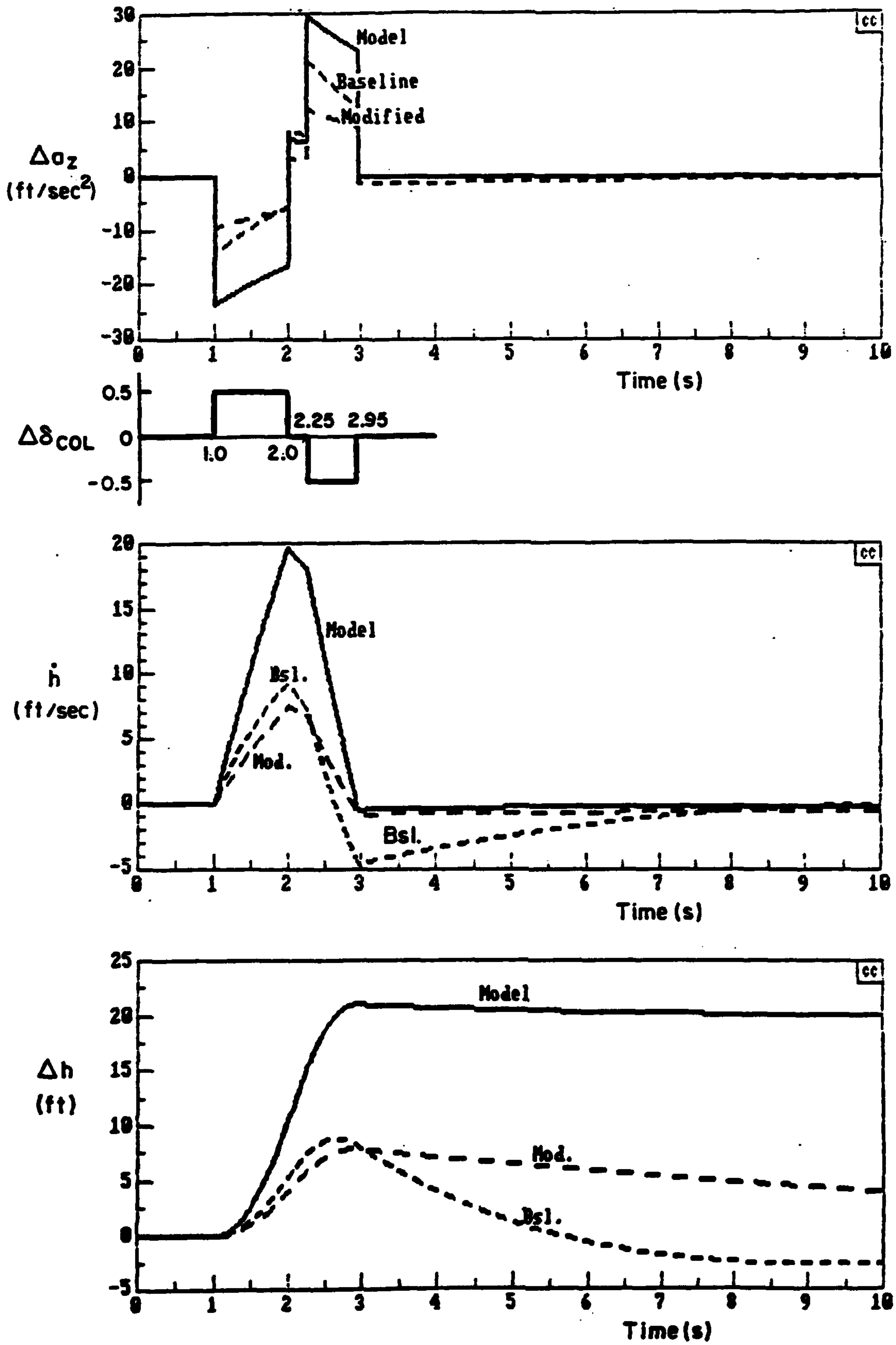


Figure 3. Vertical Responses to Rapid 20-ft Altitude Change

model with input size and timing adjusted to produce a rapid altitude change in the aircraft model of approximately 20 ft. The actual model responses are shown as solid lines in Fig. 3. The short dashed lines represent the responses of the VMS cab with the baseline motion filter (labeled "Baseline" or "Bsl."), and the long dashed lines are the responses for the modified motion system (labeled "Modified" or "Mod."). The initial collective input commanded a normal acceleration change of almost 25 ft/sec^2; because of the higher motion gain, the baseline response more faithfully transmits this command to the cab, and results in a slightly greater initial altitude rate and height change. When the second pulse is applied to stop the climb and then removed, however, the baseline system actually commands an acceleration in the opposite direction, due to the high washout frequency, to drive the cab back to center position. So while there is a commanded altitude change of 20 ft, the cab actually moves only about 8 ft, then returns toward (and even beyond) zero ft. By contrast, the modified system moves the cab about 7 ft, then back toward center at a much slower rate. The acceleration, rate, and altitude responses for the modified system more faithfully reproduce (albeit at reduced gain) the model responses.

Evaluations were also made with the motion system turned off entirely, i.e., fixed-base.

D. TIME DELAY VARIATIONS

1. Identification and Measurement of Time Delays

Confirmation of all time delays in the simulation, including documentation of the inherent delays in the model and motion elements, was performed at the start of the simulation. Timing diagrams generated by NASA personnel isolated phantom delays such as "recording delays" from those delays actually in the simulation. Values were verified using frequency-response measurements. The techniques of this verification are discussed in more detail in the next section of this report, and data plots are given in Appendix B.

Figure 2 shows the sources of time delays in the VMS facility. The delays due to the A/D and D/D (T_{AD} + T_{DD}) interfaces total about 10 msec. The model acceleration was subject to a one-cycle delay of the computer, T = 20 msec. Lead compensation in the motion drive algorithms effectively removed this one-cycle delay for commands to the motion system (i.e., T_{MD} = -T). Motion system delays, T_{MS}, were measured from frequency responses as documented in Appendix B. The VMS motion system frequency response may be characterized in any axis as a cascaded combination of a second-order lag plus time delay; for the purposes of this experiment, however, this lag-plus-delay combination may be approximated sufficiently by a pure time delay, τ_m. The estimated values of τ_m for the VMS (Appendix B) were 70 msec for pitch and roll angular velocities; 110 msec for yaw angular velocity; and 170 msec for longitudinal (surge), 100 msec for lateral (sway), and

160 msec for vertical (heave) linear accelerations. The total throughput delay for motion response to cockpit control inputs is, therefore (Fig. 2), $2(T_{AD} + T_{DD}) + \tau_m$, resulting in 90 msec in effective delay for the pitch and roll responses.

For the visual path in Fig. 2, the advancing integration from acceleration to velocity removes the delay due to computer cycle time, resulting in no net delay. The compensation filter in the CGI drive produces an effective time lead of 83.3 msec ($-T_c$) when it is active, and 0 msec when it is not. The D/D delay T_{DD} = 2 msec and is negligible. Finally, pipeline delay T_{PL} is 83.3 msec. The total delay in the cockpit visual response to cockpit control inputs is, therefore, $T_{AD} + T_{DD} - T_c + T_{PL}$ = 10 msec (compensation on) or 93.3 msec (compensation off).

2. Introduction of Added Time Delays

Two sources of additional time delay were available in the simulation, and combinations of these sources were tested. First, an effective delay was introduced into the visual scene only by turning off the visual compensation algorithm effectively introducing a delay of 83.3 msec in the pilot's out-the-window visual response, without affecting the math model and motion drive systems. Second, sample-and-hold circuits were added to the control systems in all axes (T_a = KT in Fig. 2) that provided capability for introducing pure delays corresponding to multiples of the host computer's frame time, i.e., 20 msec increments, up to 300 msec. Since this delay was immediately after the stick command, it introduced delays in all elements of the simulation — math model, visual, and motion.

E. BANDWIDTH/RESPONSE-TYPE VARIATIONS AND DYNAMICS OF CONFIGURATIONS

Because of the importance of time delay as an integral element in the test plan, it was essential that all sources of delay be identified. The diagram of Fig. 2 and supporting information in Appendix B provided documentation of all time delays. In addition to the elements shown in Fig. 3, the filtering of the cockpit force feel system effectively produces time delay as well. Force feel is provided by McFadden control loaders in the VMS cab, and since displacement commands were used to drive the simulation, the feel system is in series with the command path. As a result, any measurement of dynamics referenced to cockpit control force must account for the lags introduced by the feel system.

The dynamics of the tested configurations were characterized in terms of their pitch and roll attitude Bandwidth parameters (Ref. 10), i.e., Bandwidth frequency ω_{BW} and phase delay τ_p. Each of the time-delay sources in the VMS facility outlined in Fig. 2 can have a very large effect on the values of these parameters. For ground-based simulation, it is necessary to properly account for three separate response elements, the math model, the visual scene, and the motion system, since the pilot

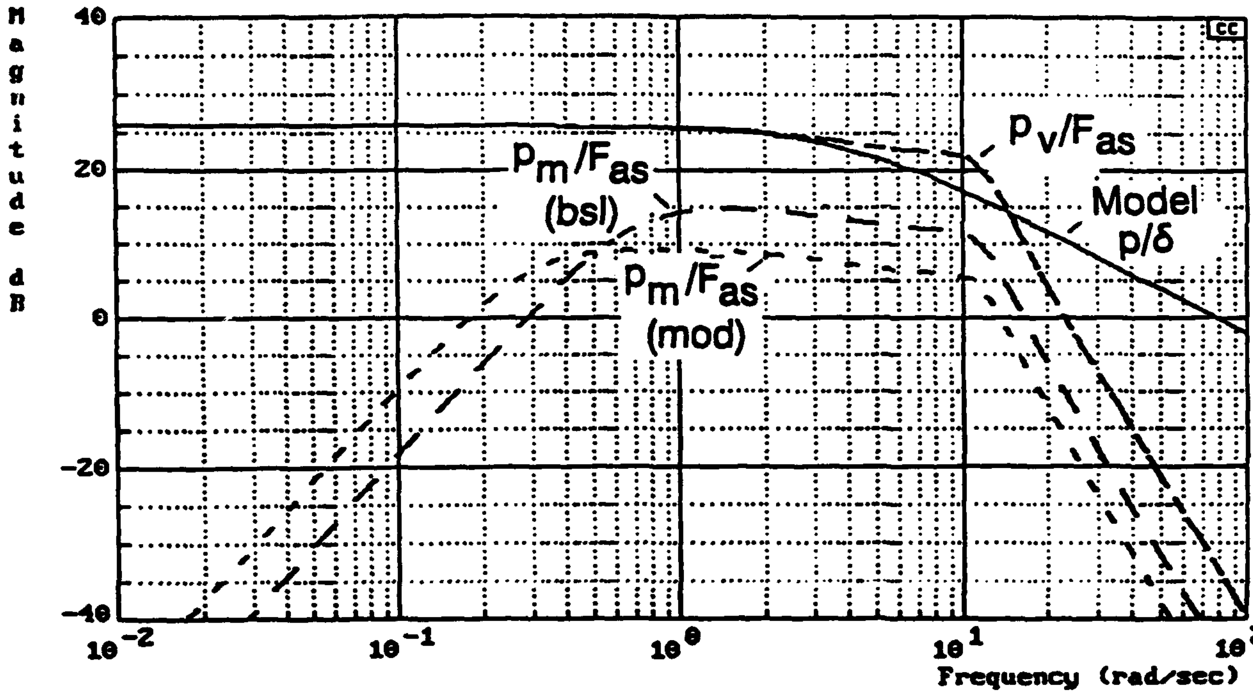
is, to some extent, aware of and operating in response to all of them. In the case of the VMS it is possible for the Bandwidths of these three responses to be quite different for the same configuration. An example of this is shown in Figs. 4 and 5.

The frequency-response plot of Fig. 4 illustrates the dramatic effects of cascading the individual elements of the simulation onto the ideal math model. The model (shown as solid lines in Fig. 4) is the high-Bandwidth Rate system (Table 2); p/δ represents the model response to measured control position (i.e., after the A/D and D/D interfaces in Fig. 2). As expected, in the absence of time delays this ideal system exhibits a Bandwidth frequency of $\omega_{BW_\phi} = -L_p = 4$ rad/sec, and phase delay $\tau_{p_\phi} = 0$.

The response of the compensated visual display (p_v/F_{as}) in Fig. 4 is referenced to cockpit control force inputs, thereby introducing two delay-inducing elements at once: the 10-msec measurement delay for the A/D and D/D (Fig. 2), and the second-order lag at 11.4 rad/sec resulting from the feel system filtering. The feel system has the most profound effect on this response; Bandwidth frequency is reduced from 4 rad/sec to 2.77 rad/sec, and phase delay from 0 sec to 0.142 sec. Turning the visual compensation filter off does not affect the magnitude curve (since, again, we are assuming this filter is effectively a pure time delay), but there is further phase lag, with $\omega_{BW_\phi} = 2.07$ rad/sec and $\tau_{p_\phi} = 0.151$ sec.

The actual response of the VMS cab (p_m/F_{as} in Fig. 4) is quite different from the model and visual responses. The combination of washout filter (from Table 3) and effective time delay of 90 msec contributes low-frequency phase lead and high-frequency phase lag. The low-frequency lead introduced by the motion washouts serves to increase the Bandwidth frequencies, with $\omega_{BW_\phi} = 3.11$ rad/sec for Baseline and 2.58 rad/sec for Modified, but the motion-system lags increase phase delay to $\tau_{p_\phi} = 0.176$ sec and 0.163 sec, respectively.

Figure 4 serves to illustrate several interesting elements of the simulation. First, it shows the significant effect of the cockpit force-feel dynamics. Second, it shows the beneficial effect of the visual compensation filter, since the phase curve of the compensated response is closer to ideal to higher frequencies (until the stick feel system dynamics swamp the response). Third, the phase distortions and gain reductions introduced by both the Baseline and Modified washouts are evident, as the responses of the ideal math model and cab roll motion are in phase for effectively only a single frequency. In addition, Fig. 4 shows that in terms of visual-motion synchronization, the <u>un</u>compensated visual response actually corresponds most closely to the motion response, especially at high frequencies. An important but subtle distinction should also be made about the effective "Response-Type" characteristics of the cab (Ref. 10): the fundamental nature of the attitude response of the



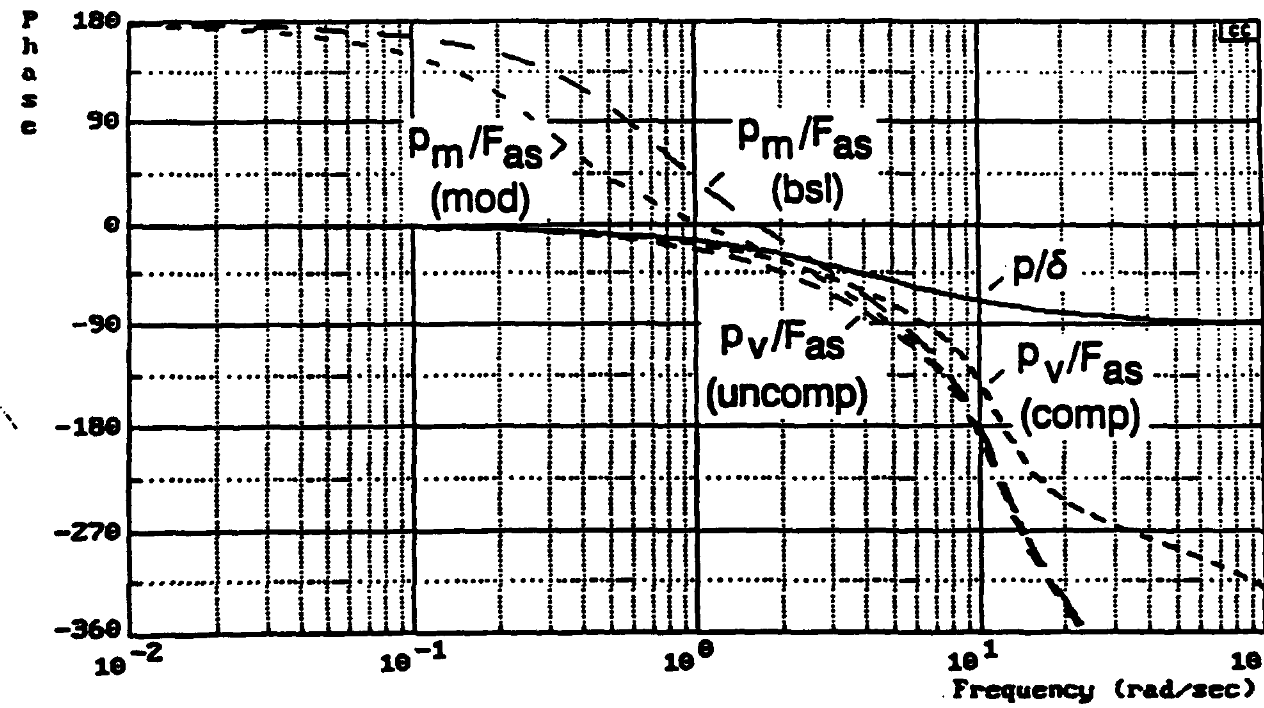


Figure 4. Frequency-Response Comparisons of Roll Rate to Control Input for High-Bandwidth Rate Response-Type (Inputs are Measured Control Position, δ, and Cockpit Control Force, F_{as}; *Outputs* are Roll Rate for Model, p, Visual Display, p_v, and Motion, p_m)

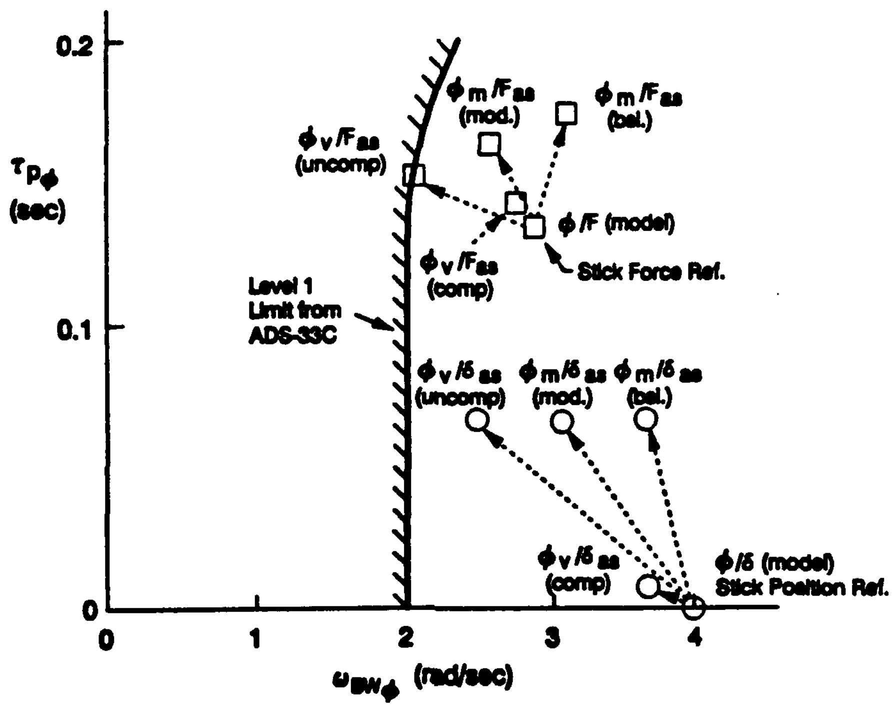


Figure 5. Migration of Bandwidth Parameters as Stick Force/Deflection, Visual, and Motion Effects are Introduced

simulator is altered from that of the model such that, while the aircraft is a Rate Response-Type, the simulator is not, due to the washout.

The significance of the Bandwidth differences for what is, effectively, a single configuration in Fig. 4, is illustrated by Fig. 5. This figure shows the ten possible measurements of the Bandwidth parameters to describe the responses of Fig. 4. The parameters for the ideal model are the most straightforward, especially for position-referenced values of measured roll rate to measured stick deflection (p/δ). The visual-display Bandwidth, with compensation on, is referenced back to cockpit control inputs, ϕ_v/δ_{as}, and hence reflects 10 msec of time delay; with compensation removed the Bandwidth drops to about 2.5 rad/sec and phase delay increases to 0.07 sec. The phase delays for motion are about equal to those for the uncompensated visual display, but with increased Bandwidths due to the washouts. Addition of the stick force feel dynamics greatly increases τ_{p_ϕ} and decreases ω_{BW_ϕ}.

Based on Fig. 5, it is reasonable to ask: which is the correct Bandwidth? Should Bandwidth be referenced to control position, or control force, or both? ADS-33C (Ref. 10) states that "It is desirable to meet the [Bandwidth] requirement for both controller force and position inputs." The issue of force- vs. position-sensing and how to treat the dynamics of the feel system has been

investigated at length (e.g., Refs. 15, 16, and 17), and there are data to support both sides. These data, along with experiences with current helicopter force-feel systems, suggest that the stick dynamics are not important as long as the force/deflection relationship is low or, equivalently, if the effective stick mass is low. A more recent analysis of all of the feel-system data (Ref. 18) concludes that the conservative approach is it is always better to reference dynamics measurements to control force, rather than position. Based on this, all analysis in this report uses force-referenced Bandwidth parameters, unless otherwise stated. The next question is — the Bandwidth of the visual response, or the motion response? This is not as easy to answer; it may be assumed, however, that the pilot's primary reference for continuous, closed-loop control is visual stimuli, with motion used to augment the visual information. Therefore the primary Bandwidth reference in this report is for stick-force-to-visual-response, ϕ_V/F_{as}.

Table 4 lists the matrix of configurations tested, including Response-Type and Bandwidth (Lo = Low-Bandwidth Rate, Hi = High-Bandwidth Rate, Table 2), amount of added time delay (in msec), whether the visual compensation filter was on or off, and if the evaluations were fixed-base. "Baseline" and "Mod. Motion" configurations refer to the motion washout filters (Table 3). The Bandwidths and phase delays of the configurations are listed in Table 4 for model, visual, and motion responses to cockpit control position and control force inputs. Bandwidths and Phase Delays of the visual pitch and roll attitude responses (control force referenced) for the configurations that were evaluated moving-base are compared with the requirements of ADS-33C (Paragraph 3.3.2.1) in Figs. 6 and 7. (They are shown in comparison with both the UCE = 1 and UCE > 1 requirements, since there is evidence that the UCE of the VMS may be worse than one, e.g., Ref. 13).

TABLE 4. MATRIX OF TESTED CONFIGURATIONS

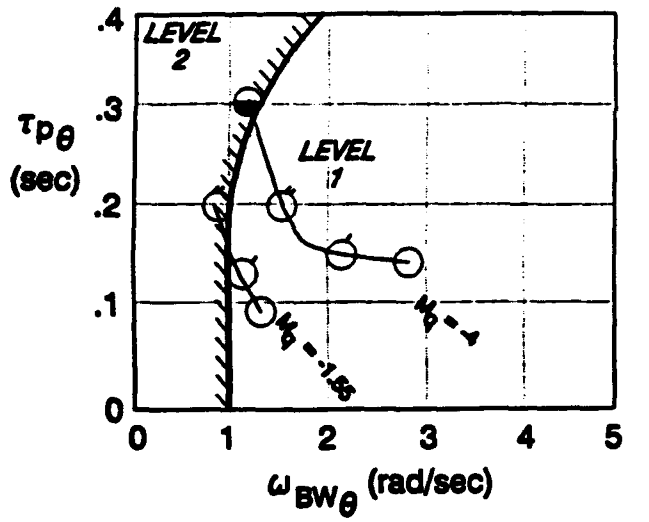
a) Control Position Referenced

Configuration	Response-Type	Added Delay (ms)	Vis. Comp. Off (x)	Fixed Base (x)	Model $\omega_{BW\theta}$	Model $\tau_{p\theta}$	Model $\omega_{BW\phi}$	Model $\tau_{p\phi}$	Visual $\omega_{BW\theta}$	Visual $\tau_{p\theta}$	Visual $\omega_{BW\phi}$	Visual $\tau_{p\phi}$	Motion $\omega_{BW\theta}$	Motion $\tau_{p\theta}$	Motion $\omega_{BW\phi}$	Motion $\tau_{p\phi}$
B (Baseline)	Rate (Hi)	0			3.72	0.008	3.72	0.008	3.72	0.008	3.72	0.008	3.45	0.066	3.63	0.067
H		80			2.51	0.065	2.51	0.065	2.51	0.065	2.51	0.065	2.76	0.122	2.93	0.124
A		0	x		3.72	0.008	3.72	0.008	2.49	0.069	2.49	0.069	3.45	0.066	3.63	0.067
E		200			1.76	0.145	1.76	0.145	1.76	0.145	1.76	0.145	2.09	0.207	2.24	0.209
D		120	x		2.20	0.094	2.20	0.094	1.75	0.147	1.75	0.147	2.53	0.149	2.71	0.149
P		300	x		1.43	0.215	1.43	0.215	1.24	0.260	1.24	0.260	1.64	0.274	1.80	0.273
B (Low BW)	Rate (Lo)	0			1.50	0.008	2.51	0.008	1.50	0.008	2.51	0.008	2.17	0.070	3.00	0.068
A		0	x		1.50	0.008	2.51	0.008	1.23	0.070	1.85	0.068	2.17	0.070	3.00	0.068
H		80			1.24	0.067	1.87	0.065	1.24	0.067	1.87	0.065	1.86	0.125	2.50	0.125
E		200			1.00	0.153	1.40	0.150	1.00	0.153	1.40	0.150	1.59	0.215	2.09	0.210
D		120	x		1.15	0.094	1.67	0.095	1.00	0.154	1.40	0.152	1.76	0.157	2.34	0.155
B (ACAH)	ACAH	0			3.89	0.008	3.89	0.008	3.89	0.008	3.89	0.008	3.59	0.067	3.76	0.069
E		200			2.51	0.159	2.51	0.159	2.51	0.159	2.51	0.159	2.64	0.221	2.73	0.219
D		120	x		2.85	0.099	2.85	0.099	2.51	0.162	2.51	0.162	2.90	0.159	2.73	0.219
B (Mod. Motion)	Rate (Hi)	0			3.72	0.008	3.72	0.008	3.72	0.008	3.72	0.008	2.57	0.163	3.06	0.066
B (Baseline FB)		0		x	3.72	0.008	3.72	0.008	3.72	0.008	3.72	0.008	---	---	---	---
A		0	x	x	3.72	0.008	3.72	0.008	2.49	0.069	2.49	0.069	---	---	---	---
L		80	x	x	2.51	0.065	2.51	0.065	1.93	0.124	1.93	0.124	---	---	---	---
E		200		x	1.76	0.145	1.76	0.145	1.76	0.145	1.76	0.145	---	---	---	---
D		120	x	x	2.20	0.094	2.20	0.094	1.75	0.147	1.75	0.147	---	---	---	---
J		260		x	1.54	0.187	1.54	0.187	1.54	0.187	1.54	0.187	---	---	---	---
G		300		x	1.43	0.215	1.43	0.215	1.43	0.215	1.43	0.215	---	---	---	---
H		220	x	x	1.67	0.161	1.67	0.161	1.42	0.211	1.42	0.211	---	---	---	---
B (Low BW FB)	Rate (Lo)	0		x	1.50	0.008	2.51	0.008	1.50	0.008	2.51	0.008	---	---	---	---

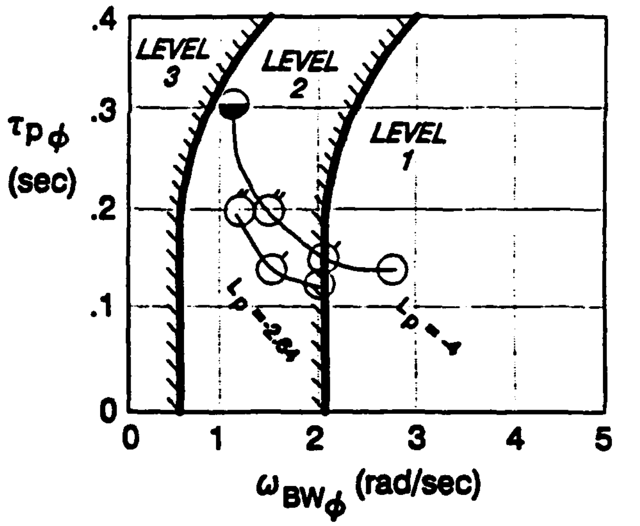
TABLE 4. (CONCLUDED)

b) Control Force Referenced

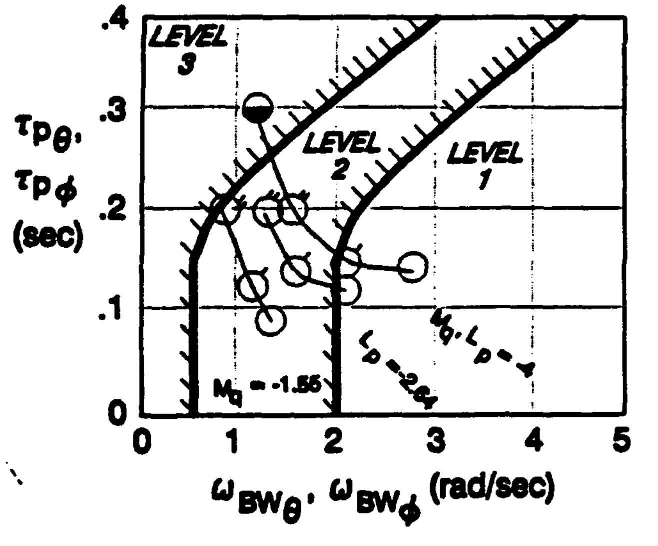
Configuration	Response-Type	Added Delay (ms)	Vis. Comp. Off (x)	Fixed Base (x)	Model ω_{BW_θ}	Model $\tau_{p\theta}$	Model ω_{BW_ϕ}	Model $\tau_{p\phi}$	Visual ω_{BW_θ}	Visual $\tau_{p\theta}$	Visual ω_{BW_ϕ}	Visual $\tau_{p\phi}$	Motion ω_{BW_θ}	Motion $\tau_{p\theta}$	Motion ω_{BW_ϕ}	Motion $\tau_{p\phi}$
B (Baseline)	Rate (Hi)	0			2.77	0.142	2.77	0.142	2.77	0.142	2.77	0.142	2.90	0.171	3.11	0.176
H		80			2.09	0.151	2.09	0.151	2.09	0.151	2.09	0.151	2.34	0.196	2.46	0.196
A		0	x		2.77	0.142	2.77	0.142	2.07	0.151	2.07	0.151	2.90	0.171	3.11	0.176
E		200			1.56	0.201	1.56	0.201	1.56	0.201	1.56	0.201	1.77	0.258	1.87	0.260
D		120	x		1.89	0.166	1.89	0.166	1.56	0.203	1.56	0.203	2.08	0.214	2.23	0.218
P		300	x		1.29	0.257	1.29	0.257	1.15	0.297	1.15	0.297	1.41	0.320	1.58	0.328
B (Low BW)	Rate (Lo)	0			1.30	0.095	2.02	0.126	1.30	0.095	2.02	0.126	1.95	0.135	2.64	0.157
A		0	x		1.30	0.095	2.02	0.126	1.13	0.126	1.60	0.137	1.95	0.135	2.64	0.157
H		80			1.12	0.126	1.62	0.137	1.12	0.126	1.62	0.137	1.73	0.181	2.28	0.192
E		200			0.93	0.199	1.27	0.198	0.93	0.199	1.27	0.198	1.50	0.264	1.81	0.265
D		120	x		1.04	0.146	1.49	0.152	0.93	0.198	1.27	0.198	1.65	0.209	2.15	0.217
B (ACAH)	ACAH	0			3.24	0.141	3.24	0.141	3.24	0.141	3.24	0.141	3.22	0.189	3.33	0.174
E		200			2.36	0.223	2.36	0.223	2.36	0.223	2.36	0.223	2.49	0.281	2.57	0.285
D		120	x		2.62	0.175	2.62	0.175	2.34	0.225	2.34	0.225	2.71	0.231	2.80	0.234
B (Mod. Motion)	Rate (Hi)	0			2.77	0.142	2.77	0.142	2.77	0.142	2.77	0.142	2.58	0.163	2.58	0.163
B (Baseline FB)		0		x	2.77	0.142	2.77	0.142	2.77	0.142	2.77	0.142	---	---	---	---
A		0	x	x	2.77	0.142	2.77	0.142	2.07	0.151	2.07	0.151	---	---	---	---
L		80	x	x	2.09	0.151	2.09	0.151	1.70	0.183	1.70	0.183	---	---	---	---
E		200		x	1.56	0.201	1.56	0.201	1.56	0.201	1.56	0.201	---	---	---	---
D		120	x	x	1.89	0.166	1.89	0.166	1.56	0.203	1.56	0.203	---	---	---	---
J		260		x	1.39	0.235	1.39	0.235	1.39	0.235	1.39	0.235	---	---	---	---
G		300		x	1.29	0.257	1.29	0.257	1.29	0.257	1.29	0.257	---	---	---	---
N		220	x	x	1.51	0.212	1.51	0.212	1.29	0.256	1.29	0.256	---	---	---	---
B (Low BW FB)	Rate (Lo)	0		x	1.30	0.095	2.02	0.126	1.30	0.095	2.02	0.126	---	---	---	---



a) All Other MTEs - UCE = 1 and Fully Attended Operations (pitch)



b) All Other MTEs - UCE = 1 and Fully Attended Operations (roll)



c) All Other MTEs - UCE > 1 and/or Divided Attended Operations (pitch and roll)

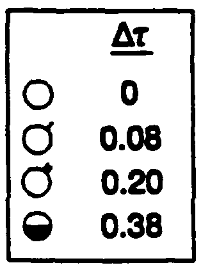
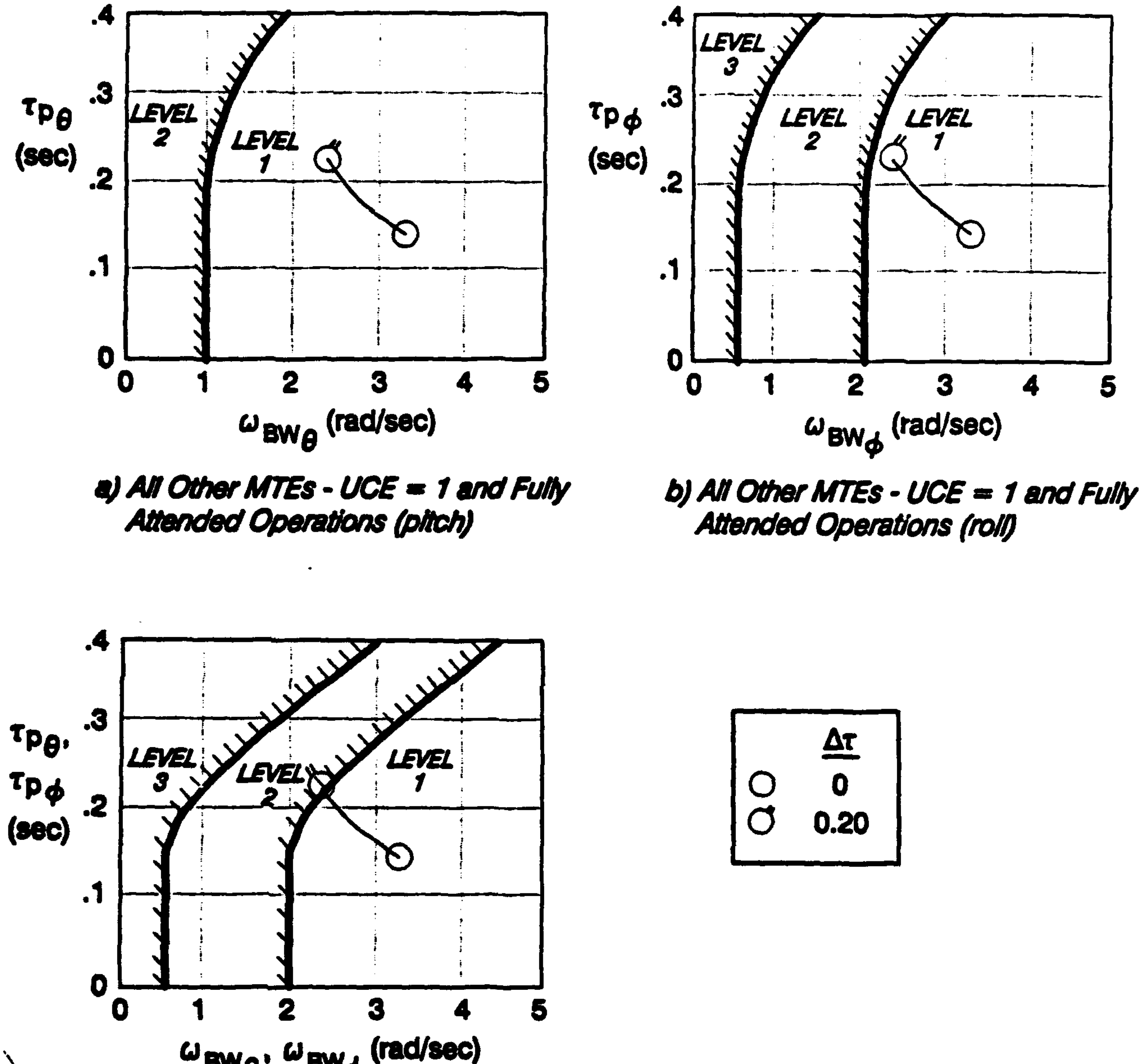


Figure 6. Comparison of Visual Bandwidths of Moving-Base Rate Response-Type Configurations with Requirements of ADS-33C (Control Force Referenced)



a) All Other MTEs - UCE = 1 and Fully Attended Operations (pitch)

b) All Other MTEs - UCE = 1 and Fully Attended Operations (roll)

c) All Other MTEs - UCE > 1 and/or Divided Attended Operations (pitch and roll)

Figure 7. Comparison of Visual Bandwidths of Moving-Base ACAH Response-Type Configurations with Requirements of ADS-33C (Control Force Referenced)

SECTION III

ANALYSIS OF RESULTS

A. DATA TAKEN

Three types of qualitative pilot opinion data were taken: Cooper-Harper Handling Qualities Ratings (HQRs, Ref. 19 and Fig. 8); Visual Cue Ratings (VCRs, Ref. 10 and Fig. 9), for determination of the Usable Cue Environment (UCE, Fig. 10); and recorded pilot comments. Since the VCRs were taken in a simulated environment, as opposed to actual flight (as required by ADS-33C), the resulting UCE does not correspond to the precise definitions of ADS-33C. The concept of a "Simulated Day UCE," or SimDUCE, is introduced in the next subsection to describe this UCE. A summary of HQRs and VCRs is included in Appendix D, and transcribed pilot comments are given in Appendix E.

Quantitative documentation consisted of frequency-response measurements of the primary configurations. These measurements were conducted in three forms: 1) perturbations of the simulation with Gaussian noise. The responses of all elements of the simulator were then analyzed on-line to generate frequency-response (Bode) plots of the visual, math model, and motion systems. Inputs for this analysis were applied in the computer software and hence were entirely open-loop. 2) Pilot-generated frequency sweeps. The responses generated were analyzed off-line after the simulation with Fast-Fourier Transform (FFT) software (e.g., Ref. 20) to independently verify the on-line results. 3) Six-axis frequency evaluation (SAFE, Ref. 21) of the motion system. SAFE applies a sum-of-sines signal to the motion system and measures the frequency response of the cab only, downstream of the washout logic (point C on Fig. 2). Hence the results of the SAFE runs provide an independent, though only partial, check of both the Gaussian-noise and frequency-sweep results. The pertinent results of all three measurement techniques are documented in Appendix A of this report.

B. CHARACTERIZATION OF THE SIMULATED VISUAL ENVIRONMENT

1. Visual Cue Ratings and Simulated Day Usable Cue Environment (SimDUCE)

ADS-33C (Ref. 10) applies the concept of the Usable Cue Environment (UCE) as a method for evaluating the effectiveness of cockpit displays and vision aids for stabilization and control in conditions of Degraded Visual Environments (DVE). The evaluation of the UCE must be made in flight, in a helicopter with a Rate Response-Type that possesses proven Level 1 handling qualities (average HQR of better than 3.5 from three pilots) in good visual conditions. Tasks to be flown consist of precision hover, vertical landing, pirouette, acceleration/deceleration (dash/quickstop),

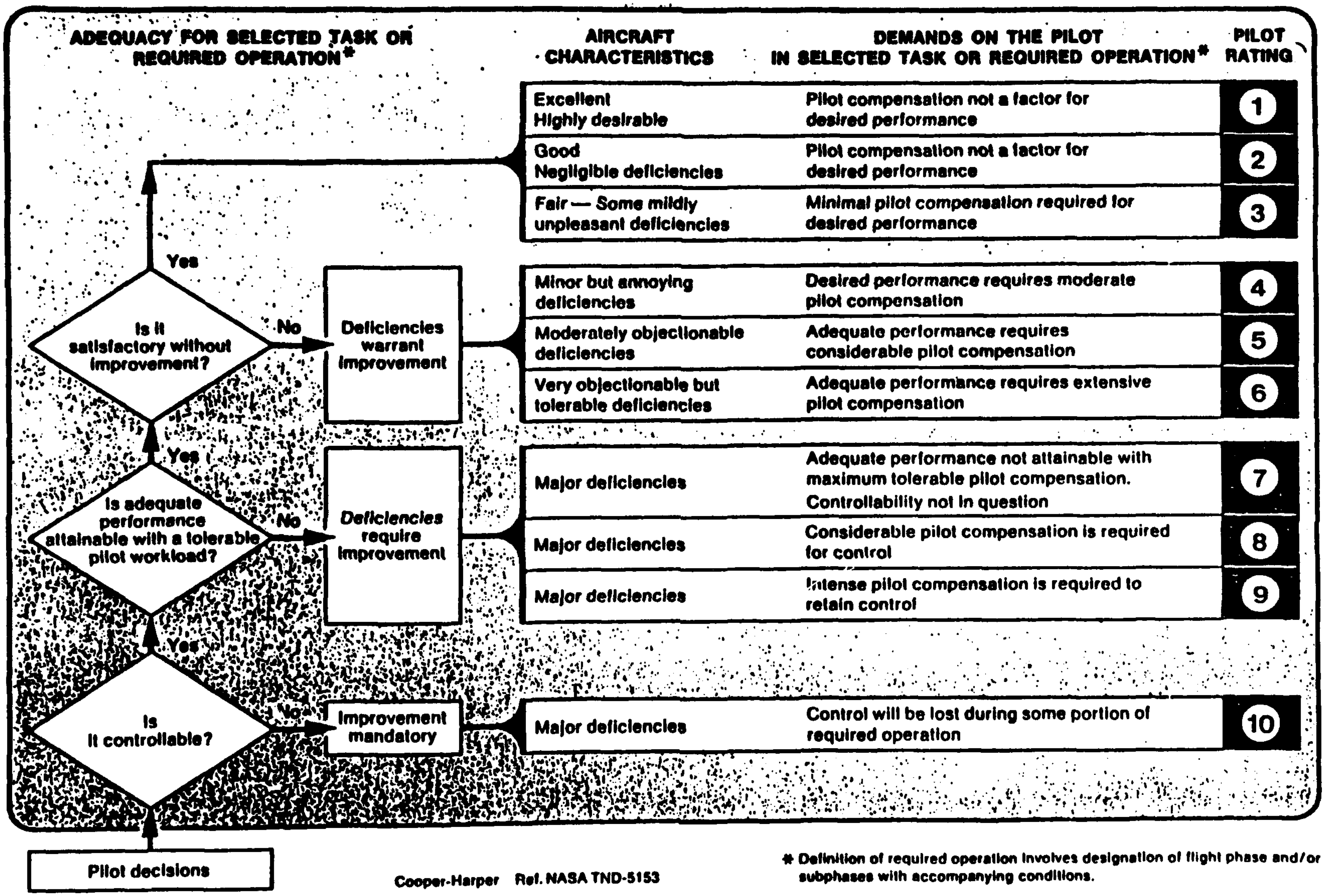
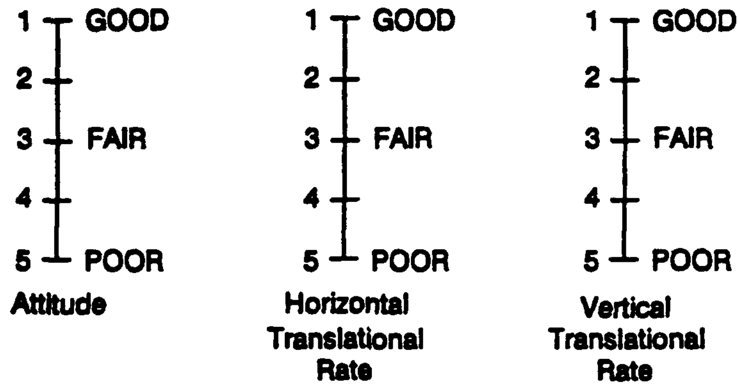


Figure 8. Cooper-Harper Handling Qualities Rating Scale (Ref. 19)



DEFINITIONS OF CUES

X = Pitch or roll attitude and lateral, longitudinal, or vertical translational rate.

Good X Cues: Can make aggressive and precise X corrections with confidence and precision is good.

Fair X Cues: Can make limited X corrections with confidence and precision is only fair.

Poor X Cues: Only small and gentle corrections in X are possible, and consistent precision is not attainable.

Figure 9. Visual Cue Rating (VCR) Scale (From Ref. 10)

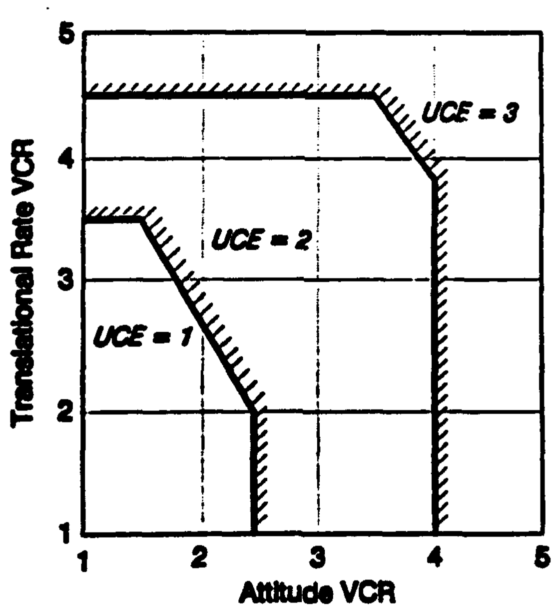


Figure 10. Definition of Usable Cue Environments (From Ref. 10)

sidestep, and bobup/bobdown. The tasks and desired-performance limits are defined in ADS-33C. Because such operations are assumed to be in a Degraded Visual Environment, the performance limits for these tasks are relaxed from those for operation in good visual conditions. In the case of rating the VCRs in the simulator, however, the interest is not in determining the effectiveness of the cockpit displays, but of the out-the-window environment. Therefore, for application to assessing the visual cue environment in the simulator, with simulated day visual cues, the same methodology is applied but the task performance standards are those for day. This simulated, day, UCE is termed SimDUCE.

Four of the evaluation pilots — Pilots D, G, S, and T — flew the full test matrix with the baseline motion system and high-Bandwidth Rate Response-Type. The overall average HQR from the pilots for all of the tasks was 3.3. Several of the tasks were modified slightly from the ADS-33C definitions, in most cases adapting performance standards to those that could be easily judged by the pilots based on outside references. In addition, because of the known limitations in attempting to perform a precision landing in the simulator, a vertical translation task was substituted for the vertical landing (see descriptions in Appendix C).

The pilots assigned VCRs for attitude, horizontal translational rate, and vertical translational rate, using the scale in Fig. 9. Application of the VCRs requires the worst of the translational rate VCRs. Table 5 lists the VCRs from the four pilots. There is an obvious disparity between pilots in their assessment of the visual cues: generally, Pilots D and S assigned VCRs of 3 to 4, indicating a degraded cue environment (Fig. 9), while Pilot G, with only one exception, assigned a VCR of 1, and Pilot T, with two exceptions, assigned a VCR of 1.5. Informal discussions with Pilots G and T during the simulation indicated that these pilots seemed to be properly applying the concept of the VCR scale, but both felt that they could be quite aggressive and precise using only the outside visual scene. Pilots D and S, by contrast, indicated in their commentary that they felt a need to be somewhat less aggressive. Average VCRs are included in Table 5 for all four pilots, and with Pilot G's ratings excluded. The overall average VCRs are around 2 to 3 in all axes, with correspondingly high standard deviations. ADS-33C requires the standard deviation between pilots to be 0.75 or less for definition of the UCE; otherwise, either more pilots are to be used, or the UCE is to be assigned by the procuring activity. In only one case (the accel/decel with Pilot G excluded) are the standard deviations less than 0.75 for both attitude and translational rate VCRs. Since the focus of this simulation was not specifically on the assessment of SimDUCE, no further attempts were made to investigate this inter-pilot variation.

Figure 11 is a crossplot of the attitude VCR and worst (higher numerically) of the horizontal and vertical translation VCRs for the four pilots. Noted beside each point is the associated HQR.

TABLE 5. VISUAL CUE RATINGS (BASELINE MOTION, HIGH-BANDWIDTH RATE RESPONSE-TYPE)

Task	VCR	Worst VCR (each pilot)				All Pilots		Pilots D,S,T only	
	Type	D	G	S	T	Average VCR (each pilot)	Standard Deviation	Average VCR (each pilot)	Standard Deviation
Hover	Attitude	3.5	1	2	1.5	2.00	0.94	2.33	0.85
	Translational Rate	3.5	1	3	1.5	2.25	1.03	2.67	0.85
Vertical Translation	Attitude	3	1	3	1.5	2.13	0.89	2.50	0.71
	Translational Rate	4	1	4	1.5	2.63	1.39	3.17	1.18
Pirouette	Attitude	3.5	1	3	1.5	2.25	1.03	2.67	0.85
	Translational Rate	2.5	1	4	1.5	2.25	1.15	2.67	1.03
Accel/Decel	Attitude	2	1	3	1.5	1.88	0.74	2.17	0.62
	Translational Rate	2.5	1	4	3	2.63	1.08	3.17	0.62
Side Step	Attitude	4	1	3	1.5	2.38	1.19	2.83	1.03
	Translational Rate	3	2	4	2	2.75	0.83	3.00	0.82
Bobup/Bobdown	Attitude	3.5	1	2	1.5	2.00	0.94	2.33	0.85
	Translational Rate	2.5	1	3.5	1.5	2.13	0.96	2.50	0.82
Total Average Attitude VCR						2.11		2.47	
Total Average Translational Rate VCR						2.44		2.86	

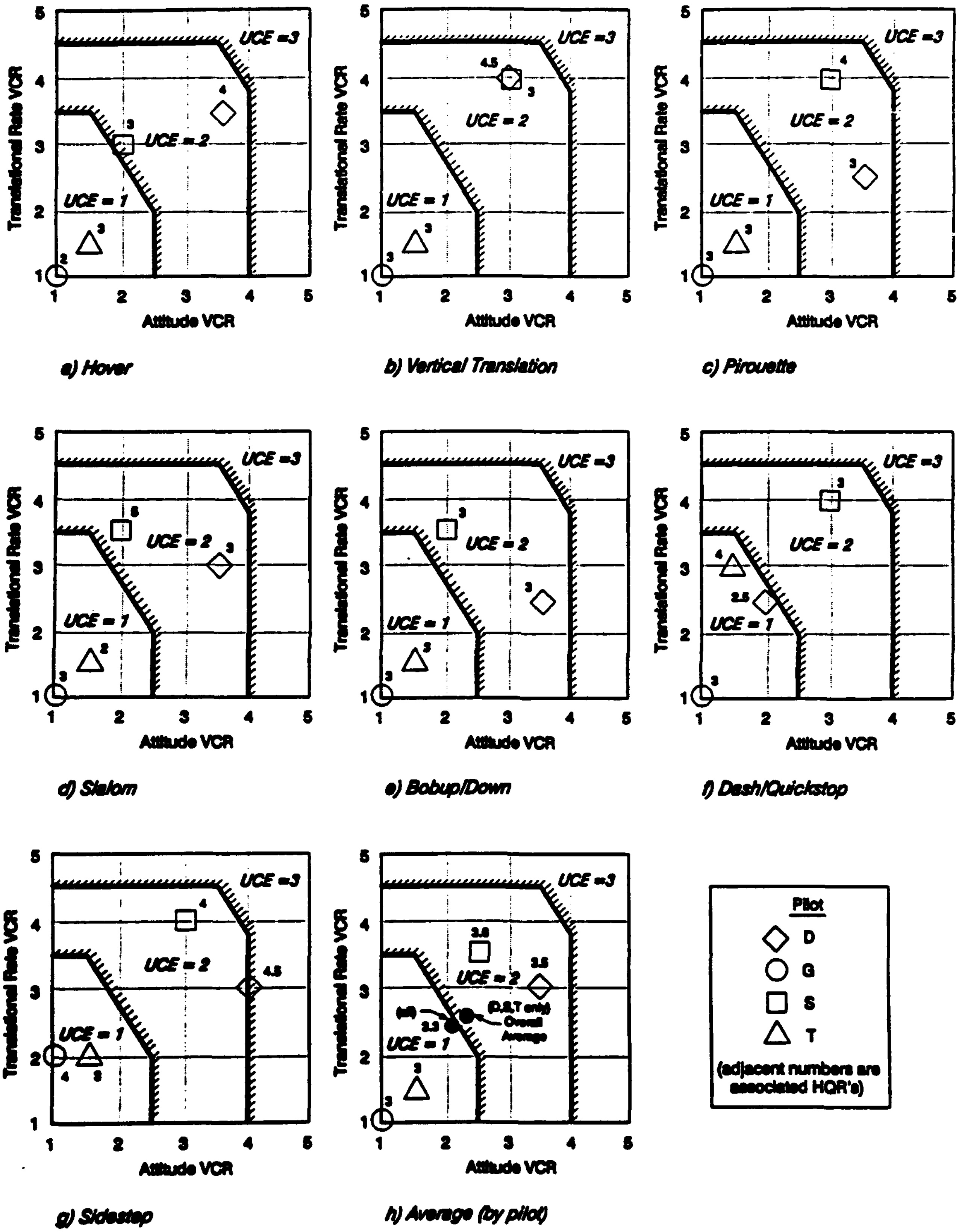


Figure 11. Visual Cue Ratings and HQRs by Task and Pilot

Based solely on the overall average VCRs in Table 5, the SimDUCE for the VMS with the DIG was a marginal SimDUCE = 1 (based on all pilots) or 2 (based on Pilots D, S, and T only).

Limited support for the designation of the simulation setup as SimDUCE = 2 comes from the VCRs assigned by Pilots M and Mc (see Appendix C), who flew only a portion of the task matrix. These two pilots, both Army pilots from the Airworthiness Qualification Test Directorate (formerly Army Engineering Flight Activity), Edwards AFB, CA, generally agreed in their assessment of the visual cues, assigning attitude VCRs of 2.75 to 4 and translational rate VCRs of 2.5 to 4 — i.e., solidly in the SimDUCE = 2 region.

2. Visual Acuity

While the determination of SimDUCE quantifies the pilots' assessment of their visual cueing environment, several other factors contribute to this environment. Principal among these is the ability to detect small changes in texture, i.e., visual acuity. Tests of visual acuity for the DIG were conducted for a simulation study of degraded visual conditions (Ref. 13). A three-bar resolution chart was programmed into the DIG visual image (Fig. 12) and the cockpit was moved to various locations relative to this chart for both clear and foggy conditions (RVR = 250 ft). The pilots' ability to distinguish the lines on this chart correspond to visual acuity, measured in terms of arcminutes/line or cycles/mrad. Figure 13 shows the results of these tests. As a point of reference, one arcminute is normal 20/20 vision. For the clear (RVR = unlimited) conditions, corresponding to the current simulation, the visual acuity was about 5 to 6 arcminutes/line. Reference 13 discusses testing in Germany to establish acuity requirements for operations with various night vision goggles, for which minimum acuity of about 0.4 cycles/mrad or 4.5 arcminutes/line was proposed. Thus the ability to resolve microtexture on the DIG was worse than a proposed minimum for operations with NVGs.

3. Field-of-View Limitations

Of secondary importance to the determination of the SimDUCE is the limited field of view provided by the VMS cab. The cab used for the simulation (FCAB) provides only a fraction of that given in flight by a typical modern helicopter (Figs. 14 and 15). This is certainly a mitigating factor in the more aggressive maneuvers, especially the sidestep, where sideward visibility is quite limited (Fig. 15). Flight testing has shown, however, that field-of-view limitations are secondary in importance to lack of acuity in the pilot's ability to perform tasks (e.g., Ref. 22).

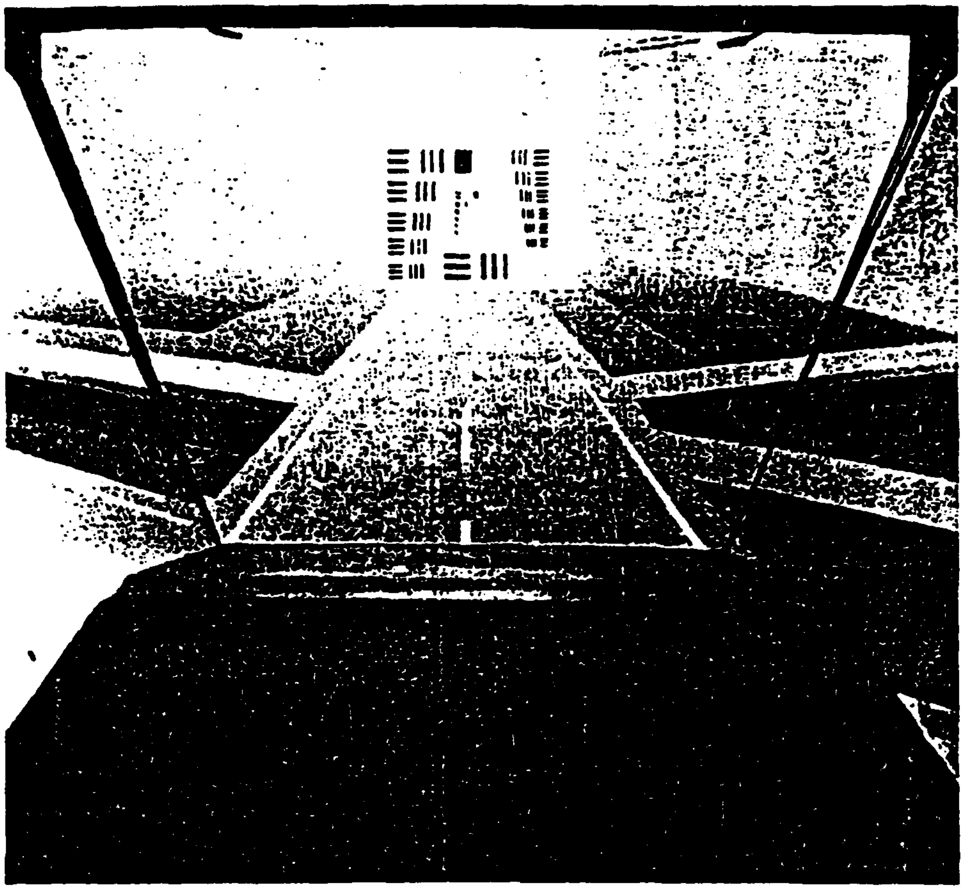


Figure 12. Three-Bar Resolution Chart (From Ref. 13)

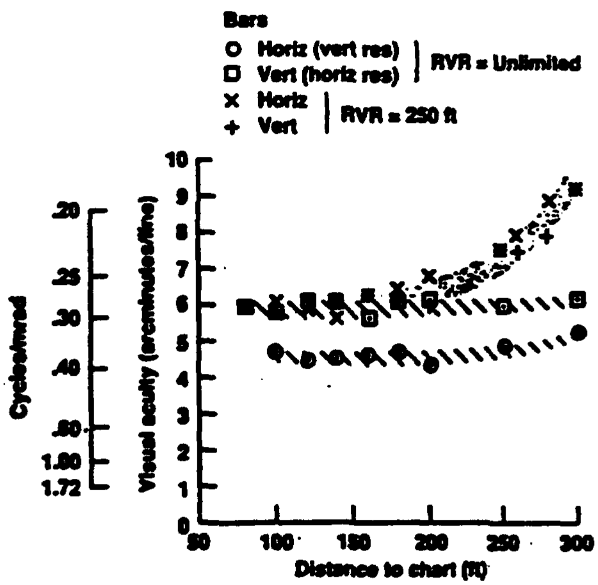


Figure 13. Resolution Results from the VMS Singer-Link DIG I (From Ref. 13)

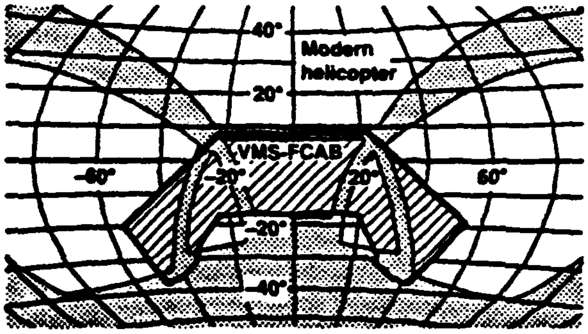


Figure 14. FCAB Display Field-of-View Plot (From Ref. 13)

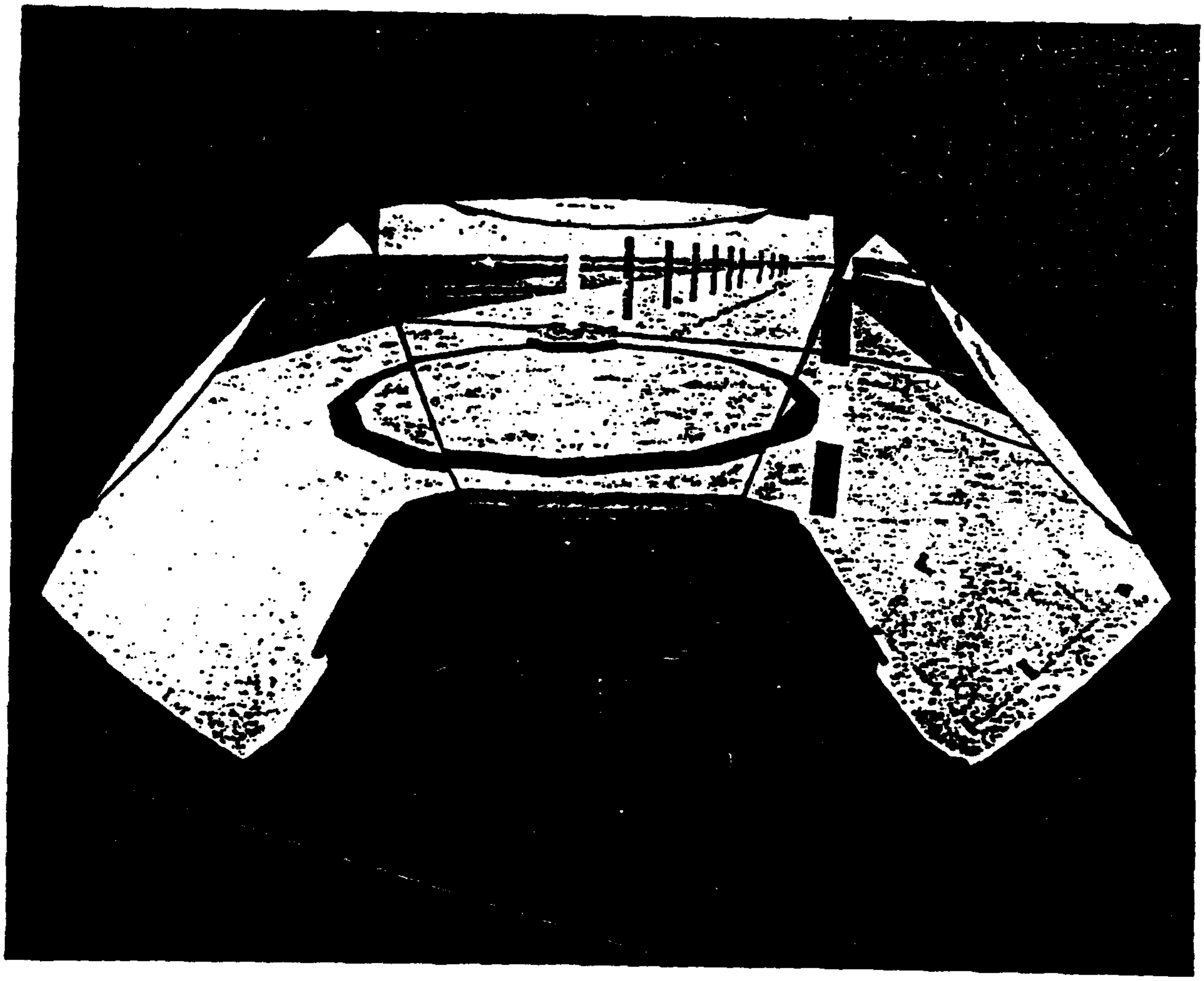


Figure 15. Visual Scene as Viewed from the FCAB Cockpit (From Ref. 13)

C. EFFECTS OF TASK AND MOTION

1. Effect of Task

Figure 16 is a plot of the HQRs for the seven tasks both fixed- and moving-base for the baseline aircraft model (high-Bandwidth Rate Response-Type, visual compensation on). Average HQRs are depicted by solid symbols that are connected by a solid line for clarity. Generally, the easiest tasks (in terms of best HQR) were the hover, bobup/bobdown, and dash/quickstop. Since no turbulence, gusts, or winds were simulated, the one-minute precision hover was low-workload as long as the pilot was reasonably well stabilized before starting the formal maneuver. Pilot comments indicated that the bobup/bobdown was relatively easy because of the decoupled helicopter model, making this almost entirely a single-axis task, while the dash/quickstop was rated well because of the ample forward field-of-view for initiating and stopping the maneuver. By contrast, the vertical translation, pirouette, and slalom maneuvers were inherently multi-axis and thus tended to receive higher HQRs, while pilot comments indicate that the high ratings for the sidestep maneuver are due primarily to the lack of a sideward field-of-view for adequately determining the endpoints of the maneuver.

2. Effect of Motion vs. Fixed Base

The benefits of motion are evident in Fig. 16: for every task, the average HQRs degrade by about one rating point when motion is removed. It is especially significant to note that motion is required to obtain Level 1 average HQRs for the baseline aircraft, which was designed to be Level 1 by the requirements of ADS-33C. Only the vertical translation and sidestep maneuvers have average HQRs worse than 3.5 moving-base, while none of the tasks received an average HQR better than 3.8 fixed-base.

3. Baseline vs. Modified Motion Washouts

Comparison of the HQRs for the Baseline set of motion washouts and gains and the Modified set in Fig. 16 shows a general trend for slightly improved ratings with the Modified set. There are exceptions, however, as the average ratings for the bobup/bobdown and sidestep tasks are slightly worse. The slight improvements for the other tasks suggest that the pilots were either aware of the more consistent motions provided by the Modified set, or, conversely, that the rapid washouts of the Baseline set mitigated the beneficial effect of the increased initial accelerations provided by the higher gains. It is likely that the answer is a blend of the two, supported by the degraded ratings for the bobup/bobdown (where initial accelerations are an important cue to the pilot) and the sidestep (where the Modified motion washouts overdrove the vertical axis in response to lateral commands).

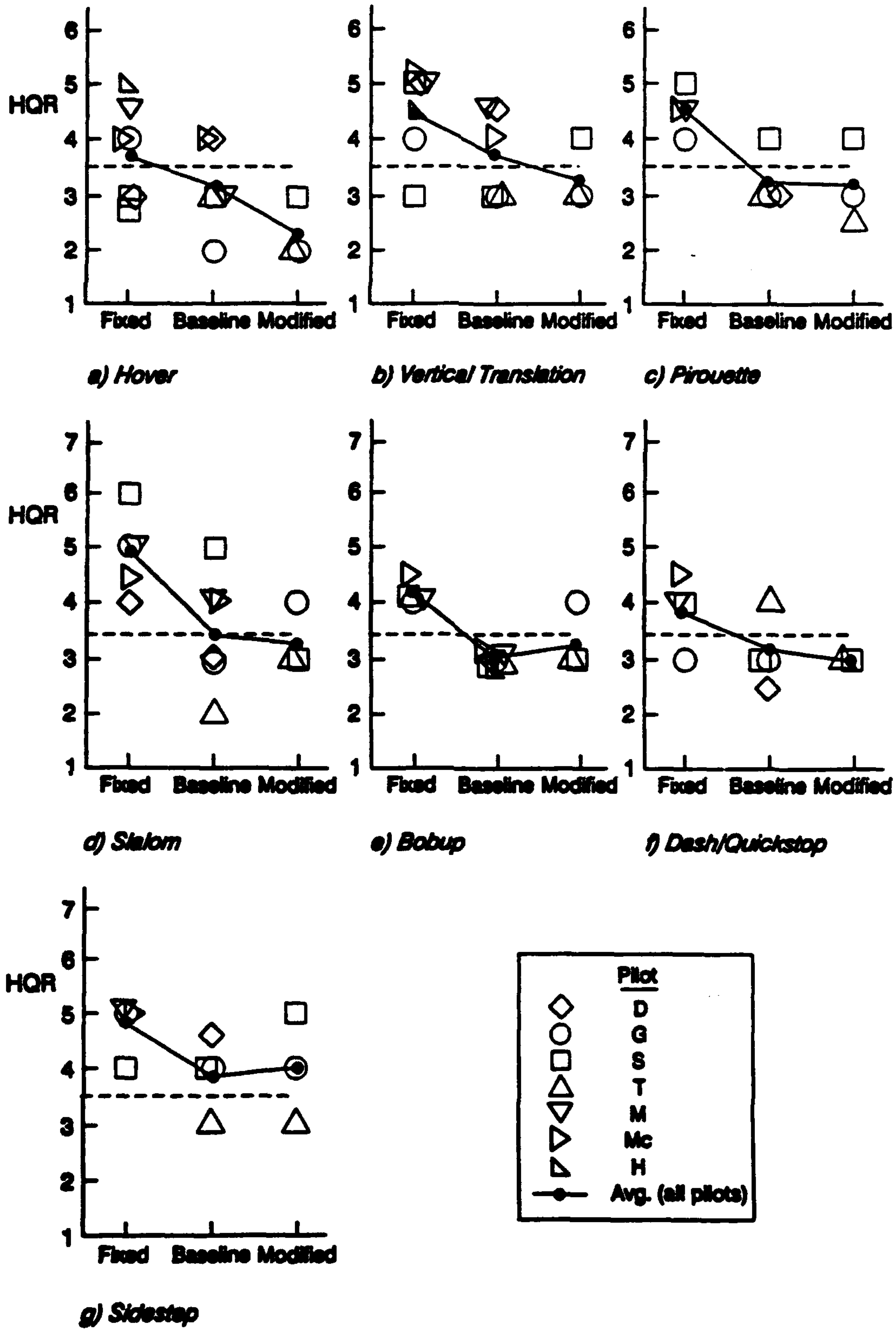


Figure 16. Effects of Task and Motion on HQRs (Baseline Aircraft: High-Bandwidth Rate Response-Type, Visual Compensation On)

The hover, vertical translation, and pirouette are classified as precision tasks in ADS-33C, while the bobup/bobdown, dash/quickstop, and sidestep are aggressive tasks. The slalom task flown in this simulation has no direct counterpart in ADS-33C but the pilots found that the most difficult part of the slalom was control of airspeed — therefore it may be considered to correspond more to a precision task than to an aggressive task.

By their nature, aggressive tasks involve rapid changes of state — i.e., large initial accelerations — compared to the precision tasks. Since the Baseline motion gains transmitted more of the initial acceleration onset cues, it might be expected that this set would be preferred for the aggressive tasks, and this is the case for the bobup/bobdown and sidestep (Fig. 16). By contrast, the Modified motion set was designed to provide more accurate phasing of the motion and visual responses, at the cost of reduced gain. Therefore, it is reasonable to expect this system to be preferred for those tasks that involve continuous closed-loop operations, such as the precision tasks, and this is the case as well.

Several important factors must be considered in comparing the HQRs for the two motion gain/washout sets: first, the Modified set as developed for this simulation was intended to be exploratory in nature, and it did not take advantage of all axes (see description in Section II); and second, since the basic aircraft was good to begin with, small changes in average HQR may or may not be significant. Further testing is required, especially to determine the possible effects of motion washouts when the handling qualities are degraded to begin with, i.e., for a Level 2 or 3 helicopter.

The Modified-motion evaluations were performed by three pilots, Pilots G, S, and T. In their commentary (transcribed in Appendix E), Pilots G and T expressed a slight preference for the Modified set, while Pilot S preferred the Baseline gains and washouts. Pilot G, a highly experienced former NASA test pilot with many hundreds of hours in the VMS, G did not indicate any dissatisfaction with the Baseline set. He was able to discern the differences between the two gain sets:

> I sense from my initial evaluation [of the modified washouts], as well as going through these formal evaluation tasks, that you have washed out some of the motion.... I like it. This is fine. I thought the motion system gave me good cueing compared to the other one [Baseline].

By contrast, Pilot T found the Baseline washouts and gains to be inadequate expressing a preference for the Modified set:

> There's a slight, very subtle increase in the value of the motion system. There's something about it that is just a little bit better for me.... It's either the feel on the seat of the pants or the correlation between motion and the eye, it's hard to tell.... I think the motion cues are just a tiny bit better on this system.

Pilot S's comments on the Baseline and Modified washouts are similar for most tasks. Pilot S had a tendency, however, to occasionally reach software motion trips with the Modified set, especially for the sidestep task, and his commentary indicates a strong negative reaction to this.

This difference in individual assessments of the motion characteristics illustrates the strong effect of piloting style and, possibly, pilot sensitivity to motion; Pilot S commented during several runs with the Modified washouts that he could feel unusual motion responses that did not correlate with the visual. Yet the comments from Pilots G and T suggest that the Modified washouts improved their assessments of the visual/motion synchronization. It is possible that the frequent trips of motion software limits by Pilot S resulted in his feeling more uncorrelated residual motion responses, as the motion both contacted the soft limits and moved away from these limits. Pilots G and T may have either hit the limits fewer times, or been less sensitive to the resulting motions. Given more simulation time, it would have been possible to adjust the modified washouts slightly to accommodate Pilot S, and re-evaluate this new set. Pilot S's HQRs, however, do not show any consistent degradation for the modified washouts; his ratings either improved or remained constant for the modified set when compared to the Baseline (Fig. 16), with the exception of the vertical translation and sidestep tasks.

D. EFFECTS OF VISUAL VS. MODEL DELAY

The effects of the location of added time delay were investigated by turning the visual compensation filter on and off. Since the filter provides an effective 83.3 msec of lead (see Section II) to compensate for the generation of visual images by the DIG, removing this filter is equivalent to introducing 83.3 msec of time delay in the visual path only, i.e., the model and motion system responses are unchanged. By comparison, an 80-msec pure delay can be introduced in the time-delay circuit in the model software that affects the entire simulation — model, motion, and visual. Several evaluations were made with both of these sources of time delay.

Figure 17 shows individual and average HQRs for the seven tasks for the no-delay case (i.e., visual compensation on, no added delays, Configuration B in Table 4), for visual-only delay (compensation off, Configuration A), and for total model delay (80-msec delay, Configuration N). The Baseline motion washouts and gains were used with the high-Bandwidth Rate Response-Type. For the four tasks where both types of delay were evaluated, there is a slight degradation in average HQRs for either source of delay. With the exception of the slalom task, the degradation is less when the delay is in the visual path only. The spread in HQRs for the slalom with visual delay indicates large scatter: two pilots rated this better than with the compensation filter on (HQRs of 3 and 3 compensation off, and 4 and 4 compensation on), while the third gave the visual-delay case an HQR of 7.

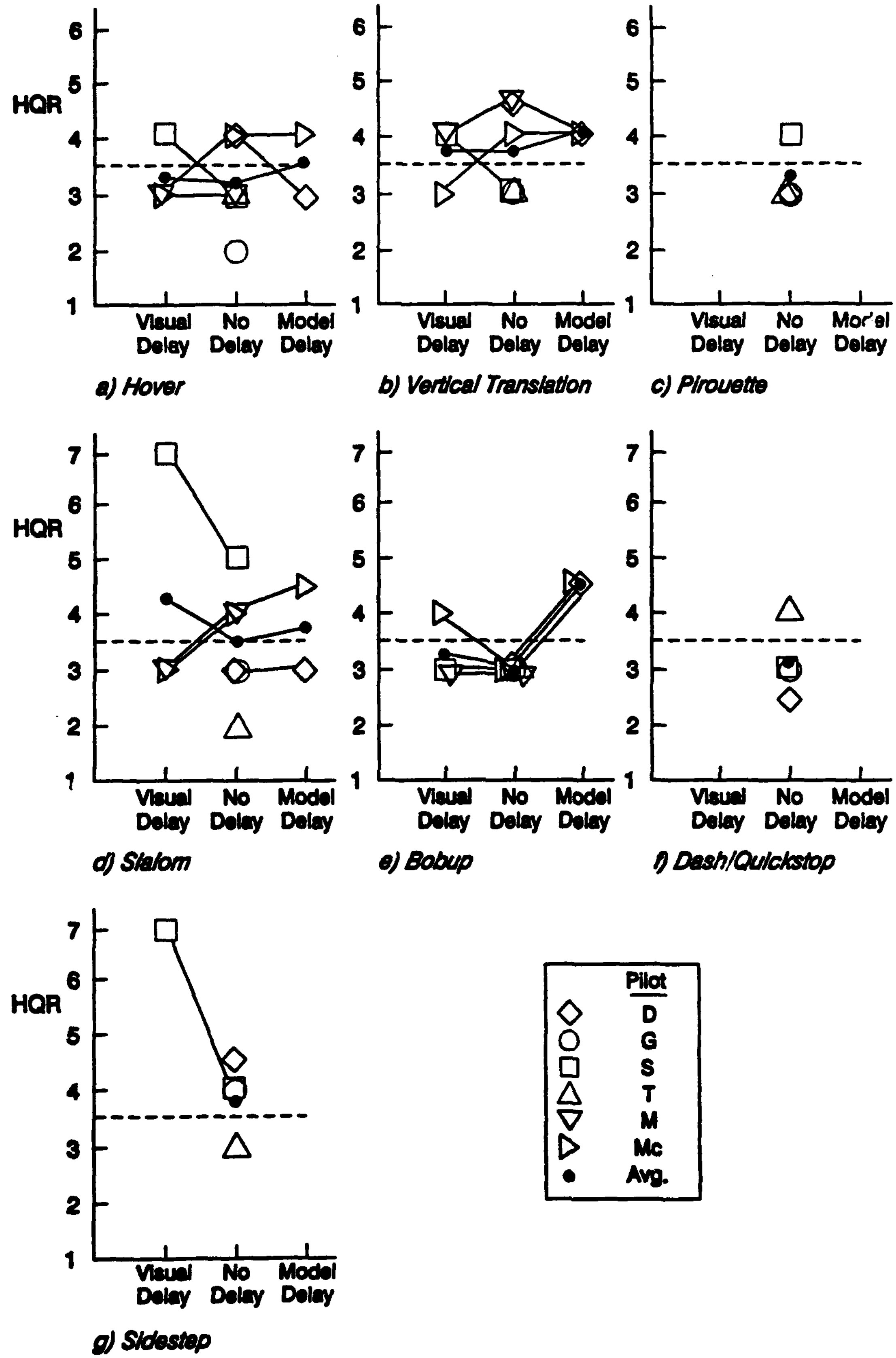


Figure 17. Effects on HQR of Introducing Approximately 80 msec of Time Delay in the Visual Scene Alone (Visual Delay), and in the Total Simulation Model (Model Delay). Baseline Motions, High-Bandwidth Rate Response-Type

Figure 17 includes HQRs from all pilots, even though only one of the seven flew all three of the time-delay variations. In terms of the added-delay evaluations, Pilots M, Mc, and S flew the visual-only case; two (Pilots M and Mc) generally preferred the visual-delay case over the no-delay case, while the third (Pilot S) was just the opposite.

Comments by Pilot S for the visual-delay Configuration A deal almost exclusively with motion problems, rather than visual. Since the Baseline motion washouts were used, and since Pilot S preferred this motion (as discussed above), it is assumed that the adverse comments about motion for these evaluations reflect the change in the motion/visual relationship. Summarizing comments from Pilot S:

> [Vertical Translation:] The first thing I'll make a comment on is that the aircraft is still wallowing around. There's some residual motion. It's like there's too much motion for the small corrections I'm seeing.... [Slalom:] The motion, again, seemed to be high. I hit the software limit, which is just devastating when you hit it.... [Sidestep:] When I start the input, I feel real subtle motion. On the arrestment, it seems like it's exaggerated, as if the input was delayed.... [Comment card:] Compare this motion system with the other systems flown in this experiment? This is probably getting close to the worst one I've flown. It's especially showing up in the lateral. Some of the others were much more precise, crisp and predictable. This one was lacking in most of those characteristics. Did the motion and visual cues seem consistent? There were times when they did not. It seemed like, especially in the [vertical translation] task, that our sense of motion was perceived as being vertical motion, and not seeing anything in the visual except maybe a slight roll oscillation. It did not appear to be consistent.... Was there any feeling of discomfort, nausea, disorientation or illness during the task? There was a little discomfort when I was getting what I perceived as motion cues in the [vertical translation] task that didn't agree with the visual, but it wasn't very strong.

Pilots M and Mc were Army test pilots from the Airworthiness Qualification Test Directorate (formerly AEFA) at Edwards AFB, with relatively little exposure to ground-base simulation. These pilots generally preferred the visual-delay case over the no-delay case because of the reduction in crispness of the response. For Pilot M,

> [Configuration A] was the least as far as the crispness goes.... There were three different motion systems I flew. The second one was kind of a little bit on the jerky side, and I had a tendency to PIO so comparing that one with other ones, it was just a little bit more difficult. This last one is more in tune.... It was easier to control.

Pilot Mc did not specifically comment on the visual response; instead, his comments for each task show a consistent difference between the no-delay case and the visual-delay case. For example, with no delay, for the hover "The problem is continuous small corrections in the lateral and longitudinal cyclic required to maintain your position. I'd say one or two in both directions every second to keep the cone from wandering a lot [HQR 4];" with visual delay, "it almost hovers by itself. You only have to compensate for drift once every five or six seconds as far as fore/aft drift [HQR 3]." For the

vertical translation with no delay, "It seems like it's very difficult to detect and maintain your position when you're moving up and down [HQR 4]," and with visual delay, "I got off slightly at the bottom because I started concentrating too hard on the cone, but it was no problem as far as noticing that I was getting off." Pilot Mc also made a general comment following the vertical translation that "The motion and the visual system seem to be more in line with each other than before. The aircraft seems to be more damped, that seems to be a good word for it."

There was also a difference of opinion when the time delay was located in the model, thus producing a uniform 80-msec delay. Of the two pilots who flew this case, Pilot D generally showed indifference to the added delay — his HQRs improved for some tasks and degraded for others (Fig. 17). For Pilot Mc, however, there was a degradation in HQR with time delay for all but the hover task, where the same rating was assigned for both the no-delay and the model-delay cases. Pilot Mc flew this configuration immediately after the visual-delay case, and his overall comments reflected his opinion of both:

> [With visual compensation off] I thought it was crisp, and I could be very precise on what I wanted it to do. The second one [80-msec model delay] didn't seem to be as stable.... It wasn't as crisp, but it wasn't sluggish.... The [visual-delay case]..., overall, felt more like flying than any of the others.... The motion and visual cues seemed to be the most consistent between my inputs, and the aircraft response, and what happened on the outside, using visual reference cues to attitude....

Significantly, Pilot Mc was able to discern the small added time delay in the model: "I thought that there was kind of a delay.... in the visual response in this last simulation. I don't know why I get that impression, but I'd make small pitch attitude changes, and I'd see the texture of the horizon change well after I made the input."

Based solely on the HQRs and comments for Pilot Mc, there is evidence that it is better to turn the visual compensation filter off, and that time delays in the visual scene are not equivalent to time delays in the overall simulation. There is some rationale for this, since the high-frequency responses of the visual scene (with the compensation filter turned off) and the VMS cab motion are nearly in phase (Appendix B), whereas the implementation of the visual filter actually increases the discordance between visual and motion responses. On the other hand, the HQRs of Pilot S are exactly opposite those of Pilot Mc, suggesting that the pilots' HQRs were heavily influenced either by their preconceptions of how the helicopter should fly, or by their experience (or lack of experience) with the flying the VMS. Neither hypothesis can be resolved using the data generated here, and it is clear that more simulation time will be required to determine any concrete, consistent differences.

Some further information can be obtained by looking at the evaluations of four other sets of time-delay configurations. These configurations had a nominal time delay of 200 msec — first

through the delay circuit, producing a pure delay in response to commands of 200 msec, and then by turning the visual filter off, introducing 83.3 msec of visual delay in combination with 120 msec of pure delay. Thus, in the latter case, the time delay is a combination of visual and model, and since the model delay occurs first, the overall visual delay is 83.3 + 120 msec = 203.3 msec, while the math model and motion delays are only 120 msec.

The HQRs for the four delay cases are plotted in Fig. 18. As for Fig. 17, the ratings are plotted by task, and the no-added-delay (visual compensation on) ratings are shown for comparison. Two configurations were flown fixed-base (Figs. 18e, 18f, and 18g), where it appears that the degradation in HQR with delay is slightly less for the model-delay case than for visual-plus-model. The HQRs shown for the moving-base tasks (Figs. 18a through 18d) are for two different Response-Types: the low-Bandwidth Rate system for Pilot T (triangles) and ACAH for Pilot D (flagged diamonds). For these, the degradation in HQRs is almost uniformly smaller for the visual-plus-model delay combination than for model delay alone. This is in agreement with the ratings of Pilot Mc in Fig. 17, i.e., the net effect of added time delay is lessened if it causes the motion and visual scene responses to be more in phase.

It is clear that much more work must be performed in this area before any quantitative conclusions can be drawn. Despite the evidence, it seems unreasonable to think that <u>increasing</u> delays in any element (e.g., turning off visual compensation filters) is desirable. There is some substantiation for this, however, from other studies of pilot performance in the presence of visual and motion delays. Several of these studies are described in Appendix A.

E. EFFECTS OF ADDED TIME DELAYS

In addition to the visual-vs.-motion delay study, several values of total delay were evaluated (Table 4). These cases consisted of both pure model delays, and combinations of model delay with the visual compensation removed. Because of the relatively small differences between the two sources of delay in the ratings of Figs. 17 and 18, for this analysis it will be assumed that the effects of total model delay (i.e., pure delay circuit) are identical to those of model delay with the visual compensation filter off. For example, in this subsection we will lump the nominal 80-msec-delay ratings of Fig. 17 together, regardless of the source, and likewise the 200-msec-delay ratings of Fig. 18.

The HQRs for all values of time delay, for the high-Bandwidth Rate Response-Type, are plotted in Figs. 19 (fixed-base) and 20 (moving-base). The flagged points are those for which 83.3 msec of the total added delay is due to turning the visual compensation off. Both figures show the expected degration in HQR with added time delay, with similar trends both fixed-and moving-base. The largest

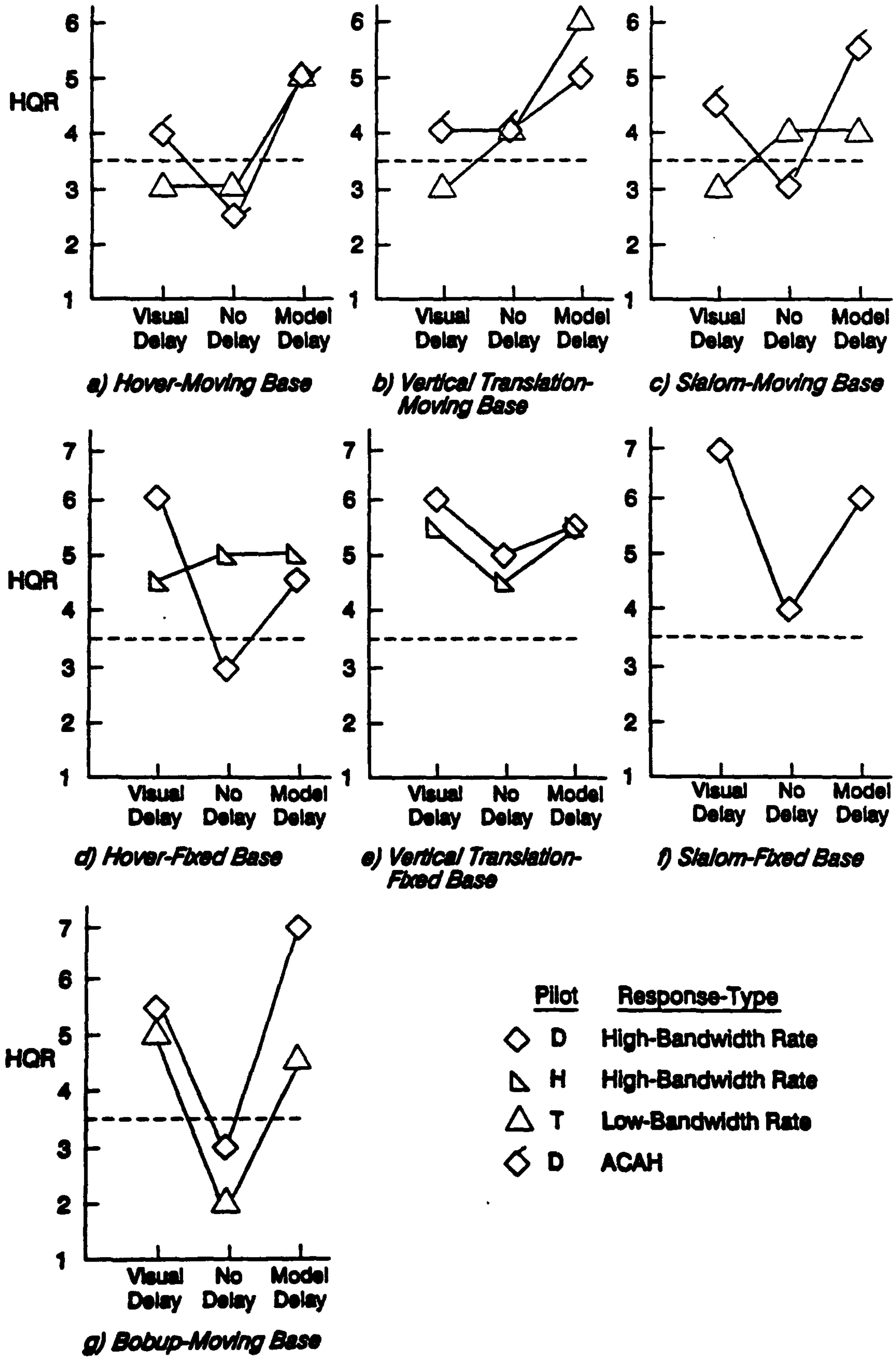


Figure 18. Effect of Combined Visual-Plus-Model Delay vs. Pure Model Delay — Nominal 200 msec Delay

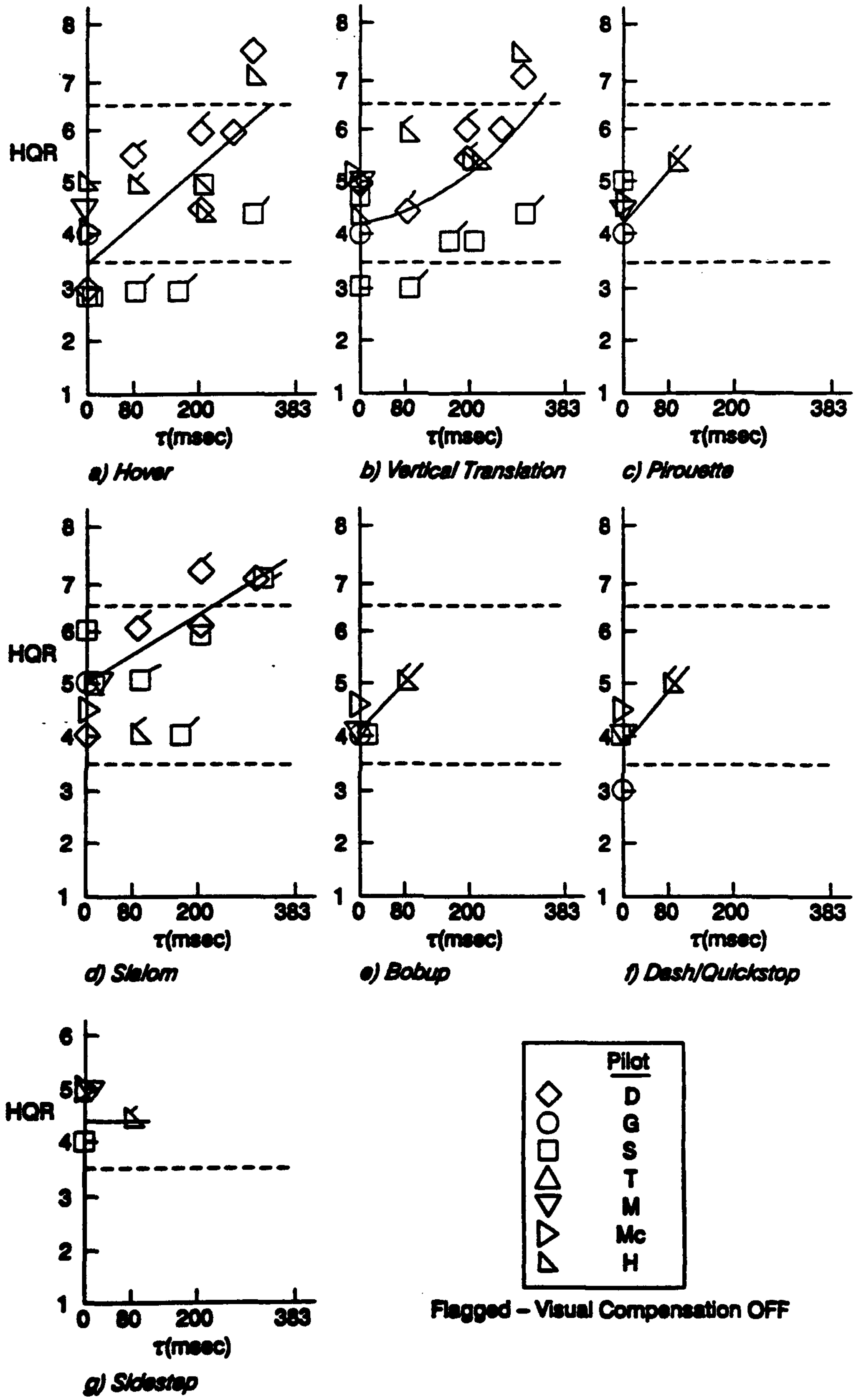


Figure 19. Time Delay Variations — Fixed Base

differences are in the total pilot rating scatter, which is greater for the fixed-base ratings, and the generally poorer HQRs fixed-base. Both of these trends have been discussed previously.

It is significant that the degradation in HQRs is such that Level 2 average ratings (moving-base) result when the total added delay is only about 80 msec (Fig. 20). This value of delay corresponds almost exactly to the point at which the Bandwidth of the visual response to control force inputs becomes Level 2 for roll (UCE = 1), and for pitch and roll (UCE > 1), Figs. 6b and 6c. Added delay as high as 200 msec is still Level 2, while the lone case with 383 msec of delay was consistently rated Level 3 (for which the pitch and roll Bandwidths are Level 2 or 3, depending upon UCE, Fig. 6).

F. EFFECTS OF RESPONSE-TYPE

Three basic Response-Types were evaluated (Table 4): ACAH, low-Bandwidth Rate, and high-Bandwidth Rate. The latter was used for most of the evaluations. The HQRs for these Response-Types are shown in Fig. 21 for the seven tasks, both fixed- and moving-base. For clarity the ratings are shown as averages, with maximum and minimum HQRs and number of ratings per data point also shown. Only two evaluations were made of the ACAH Response-Type, so the results for this system must be considered preliminary at best. The trends are generally as expected, e.g., increasing Bandwidth for the Rate Response-Type made most of the tasks easier and hence lower ratings; further improvement was found by going to the ACAH Response-Type, which is defined by ADS-33C as an increased Response-Type. These trends were not true for all tasks, however: the rating trends are reversed for the bobup, dash/quickstop, and sidestep tasks. The differences in average HQR for the low-Bandwidth and high-Bandwidth Rate systems in the bobup are not significant. The slight degradation in HQR for the ACAH Response-Type in the bobup is somewhat surprising for an almost entirely vertical task, but it is also based on only two ratings, single ratings of 3 and 4. Similarly, the results for the dash/quickstop and sidestep suggest that the pilots preferred Rate over Attitude (as expected because of the large sustained attitudes required, resulting in sustained control forces with ACAH), and low-Bandwidth Rate over high-Bandwidth (based on one fixed-base evaluation by one pilot, and hence not significant).

G. COMPARISON WITH ADS-33C

The Rate and ACAH Response-Type configurations were compared with the Bandwidth requirements of ADS-33C in Figs. 6 and 7. These figures are repeated as Figs. 22 and 23, with the average HQRs from the hover task noted beside the data points (as indicated in Section II, each configuration has two Bandwidth/Phase Delay points — one for pitch, one for roll). The agreement for the Rate Response-Types (Fig. 22) is excellent, as the three cases that are Level 1 in all plots

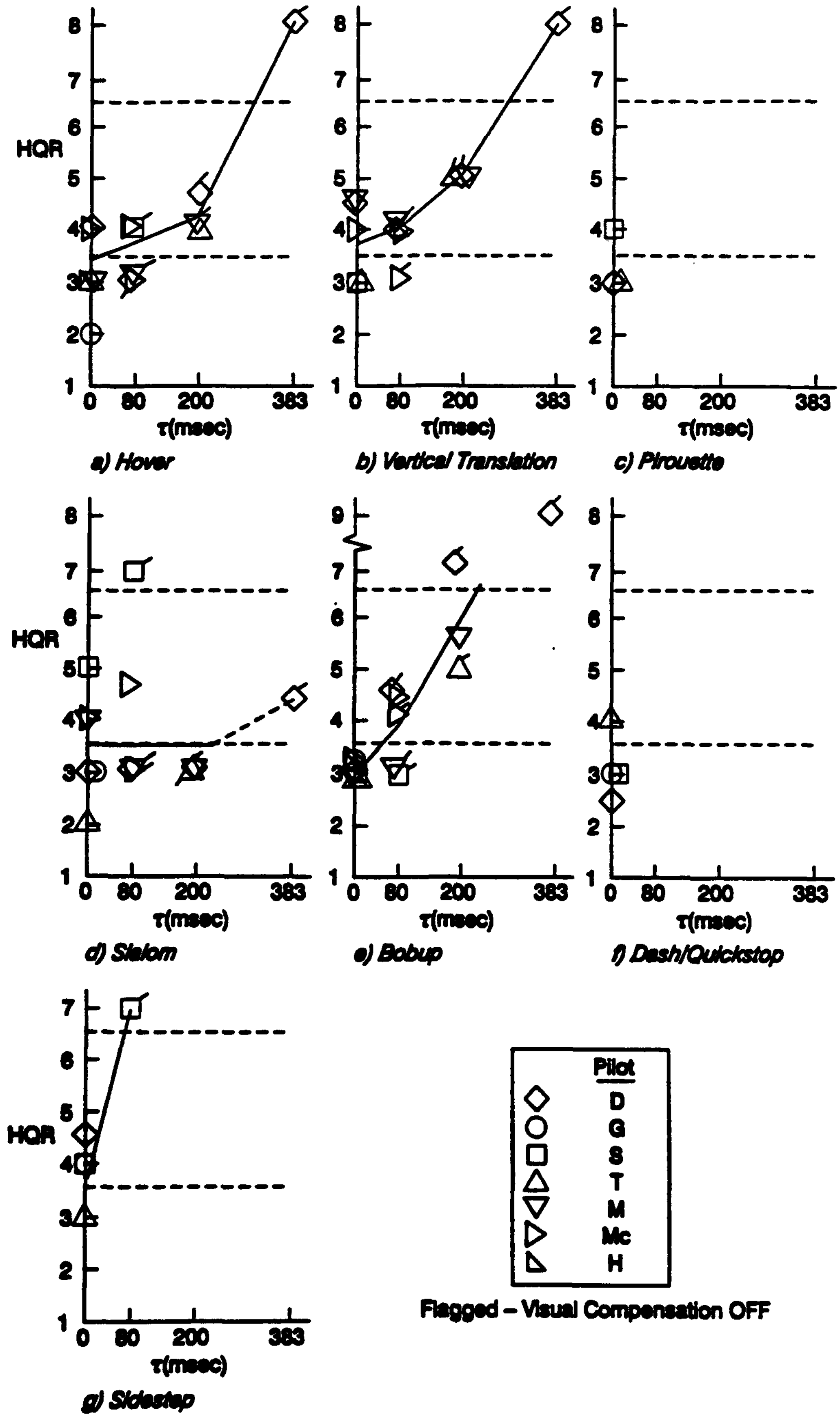


Figure 20. Time Delay Variations — Moving Base

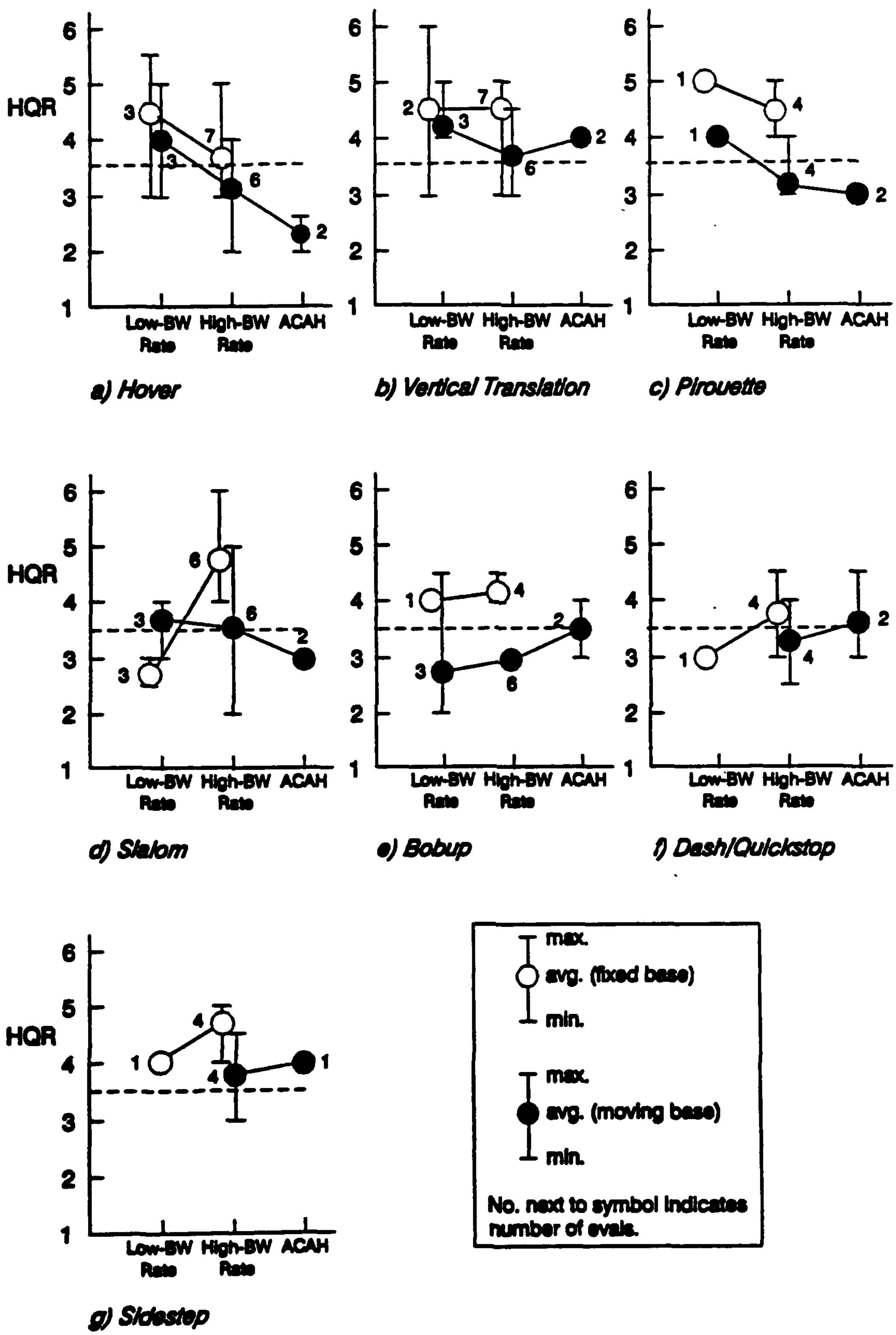


Figure 21. Effects of Bandwidth and Response-Type on HQRs
(No Added Time Delay, Visual Compensation On,
Baseline Motion)

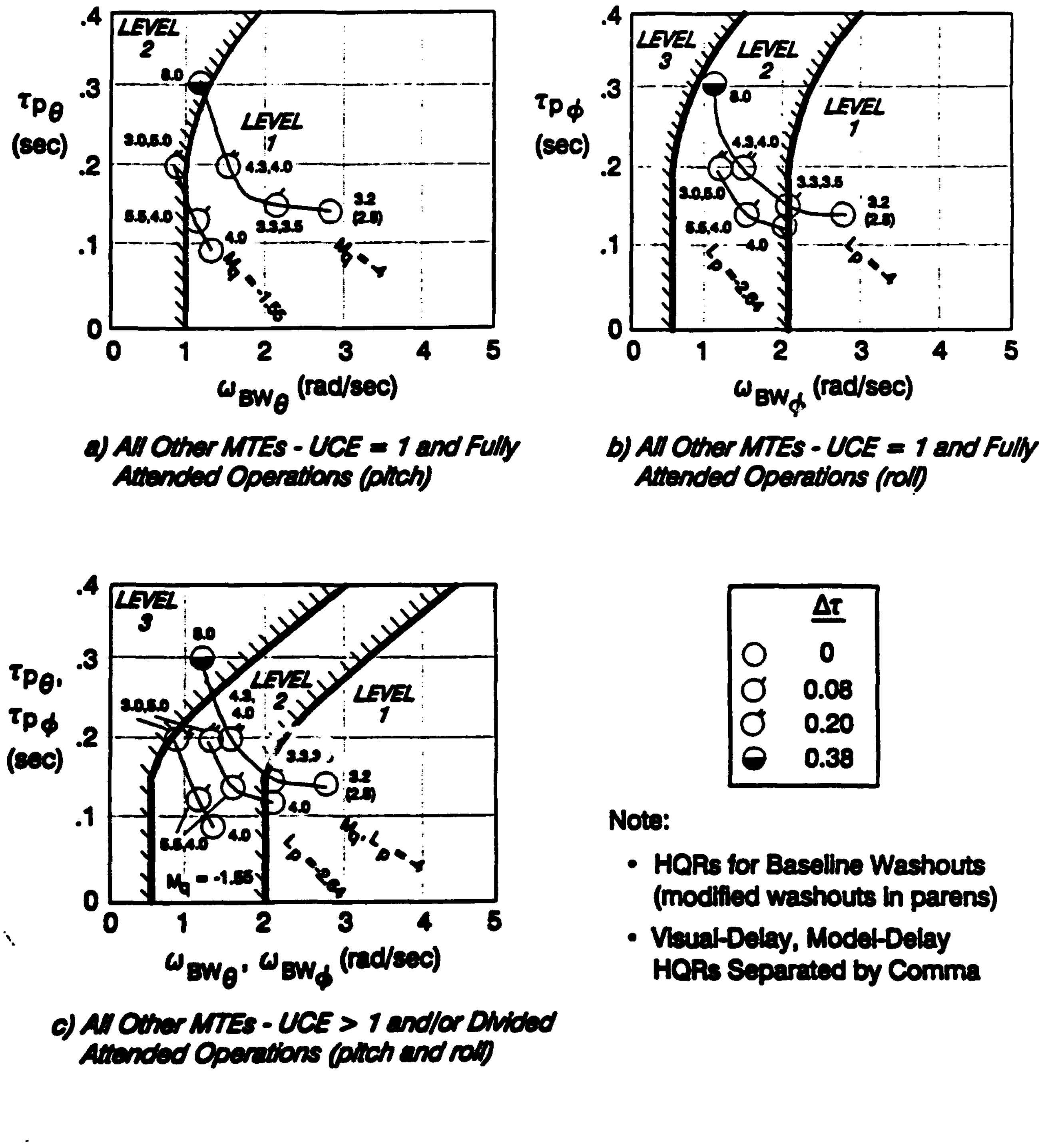
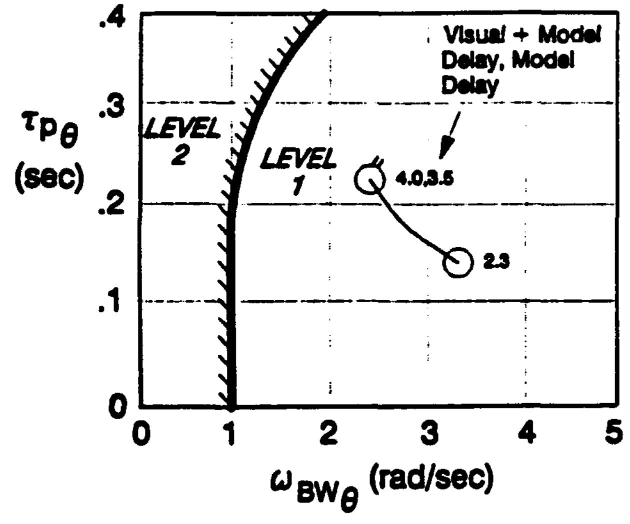
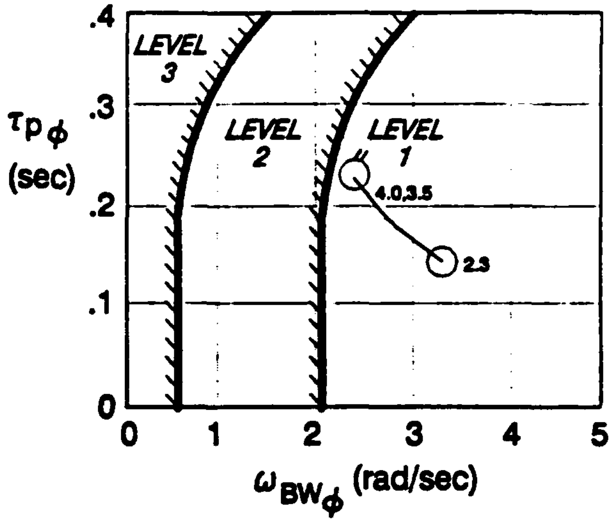


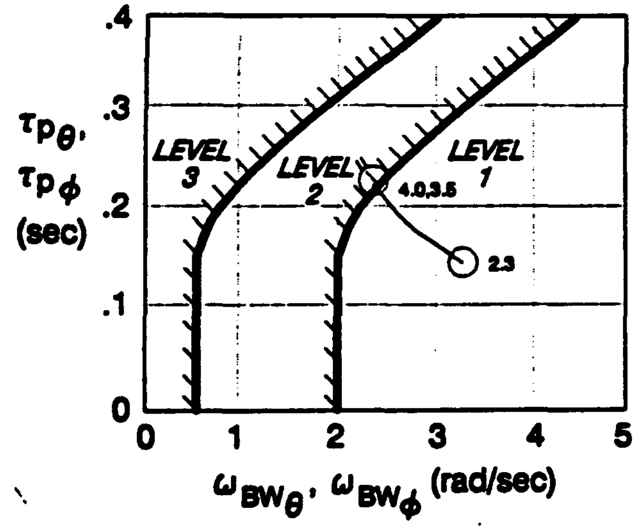
Figure 22. Comparison of Rate Response-Type Configurations with Low-Speed Bandwidth Requirements of ADS-33C (Average HQRs for Precision Hover)



a) All Other MTEs - UCE = 1 and Fully Attended Operations (pitch)



b) All Other MTEs - UCE = 1 and Fully Attended Operations (roll)



c) All Other MTEs - UCE > 1 and/or Divided Attended Operations (pitch and roll)

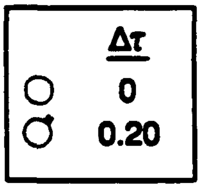


Figure 23. Comparison of ACAH Response-Type Configurations with Low-Speed Requirements of ADS-33C (Baseline Motion Washouts; Average HQRs for Precision Hover)

received Level 1 average HQRs. All but one of the cases in the Level 2 region received Level 2 HQRs (the exception was a single evaluation of the 203-msec high-Bandwidth configuration, where an HQR of 3 was assigned). The worst case (with 383 msec of time delay) received a single HQR of 8; it lies in the Level 3 region for pitch and roll for degraded UCE (Fig. 22c), and in the Level 2 regions for both pitch and roll in good UCE (Figs. 22a and 22b), and hence may be expected to receive either Level 2 or 3 ratings. In summary, only the single-evaluation case with an HQR of 3 disagrees with the ADS-33C boundaries for Rate Response-Types.

Only three ACAH Response-Type cases were evaluated (Fig. 23), so the trends are not as obvious. All three cases are in the Level 1 regions for the UCE = 1 requirements, but one case (with 203 msec of time delay — 120 msec pure delay plus visual compensation off) received a single HQR of 4. This case is in the Level 2 region for degraded UCE (Fig. 23c), and is therefore in agreement with these boundaries.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

This study of the interactions of simulator motion, visual, and response dynamics on rotorcraft handling qualities has both confirmed previous observations and revealed areas deserving of more indepth study. Unlike most previous motion/visual simulation studies, the primary goal of this study was the measurement of these interactions on perceived handling qualities, rather than on objective performance measures.

The most significant conclusions and outcomes from the simulation are summarized in this section. Since the simulation was intended to be exploratory in nature, recommendations for a more formal investigation are also made.

A. DEFINITION OF THE SIMULATION ENVIRONMENT

1. Bandwidth Measurements

For a real aircraft in the real world, measurement of the vehicle's Bandwidth and phase delay parameters is relatively straightforward: it is the response of angular attitude to the appropriate control input. The only issue to be resolved, in general, is whether the reference control signal should be displacement or force.

For a simulated aircraft in a simulation environment, however, things are much less clear. In preparation for this experiment, it was recognized that the response of the simulated vehicle could be characterized in terms of several output/input relationships, consisting of the angular attitude responses of the math model, the visual display, and the motion system. Mismatches in the responses of the visual and motion systems, resulting from such factors as motion lags and washouts and visual delays, will produce a concomitant mismatch in the Bandwidths of each individual component. All analysis in this report was based on the assumption that the pilot's primary source of information for continuous, closed-loop operation came from the visual computer-generated imagery, and therefore all Bandwidth measures have been based on this reference output signal. Recent studies have indicated that the most appropriate reference input signal is control force, rather than position, and this has been used in this report as well. The mismatch between visual and motion Bandwidths should be considered as factors in the measurement of the response dynamics of any simulation facility.

The baseline helicopter model used for most of the evaluations in this study was designed to exhibit Level 1 handling qualities for the best combinations of visual and motion response. This objective was met based on the average Handling Qualities Ratings (HQRs) for the seven tasks.

2. Simulated Day Usable Cue Environment (SimDUCE)

The concept of the Simulated Day Usable Cue Environment (SimDUCE) has been defined to characterize the method of measuring the usefulness of the out-the-window scene for stabilization and control. By definition in ADS-33C, UCE is intended to be a method of evaluating displays and vision aids in a degraded visual environment. For such operations, a special set of maneuvers, with relaxed performance limits, is included in ADS-33C. Application of the UCE concept for SimDUCE requires the application of the day, good-visual-condition maneuver set from ADS-33C, with their more stringent performance limits. The Usable Cue Environment thus measured represents the simulated, day, UCE, or SimDUCE.

Based on a full evaluation of the visual cues on the VMS with baseline motion and Digital Image Generation (DIG) visual systems and with a Level 1 helicopter, the Visual Cue Ratings (VCRs) from four pilots suggest that the SimDUCE was on the border between 1 and 2. Limited evaluations by two other pilots support defining the overall SimDUCE at 2.

3. Field-of-View and Visual Acuity

The resolution of the visual imagery with the DIG display was measured on a previous simulation (Ref. 13) to be about 5 to 6 arcminutes/line, where one arcminute/line corresponds to 20/20 vision. This lack of resolution, combined with the limited field-of-view compared to actual aircraft, had a definite effect on the perceived handling qualities in this experiment. The extent of this effect was not investigated, however.

B. EFFECTS OF TASK

Overall, Handling Qualities Ratings (HQRs) were better for the hover, bobup/bobdown, and dash/quickstop tasks. Ratings were worst for the sidestep, where limited sideward field-of-view interfered with the pilots' ability to judge the stopping points.

C. EFFECTS OF MOTION AND VARIATIONS IN MOTION WASHOUTS

A review of motion system and visual/motion tradeoff studies was conducted as a part of this simulation and is documented in Appendix A. As a part of this review, several potential guides for motion washout design were investigated. Time constraints in this simulation did not allow for a thorough evaluation of these design guides, but such an evaluation should be performed.

Motion was necessary to obtain satisfactory handling qualities: none of the tasks received Level 1 average HQRs fixed-base. Improvements in HQRs when motion was added were generally 1/2 to 2 rating points.

The baseline set of motion washouts, consisting of linear second-order filters, was designed by NASA personnel and reflected the philosophy of imparting high initial onsets (accelerations) to the pilot, with rapid washout of the resulting motions. A modified set of motion parameters with reduced washouts and decreased motion gains was developed during the simulation (Appendix A). The modified set emphasized mid-frequency dynamics, based on the assumption that the phase error between the desired aircraft response and the simulator response around the frequencies for piloted control, approximately 0.5-5 rad/sec, should be minimized. Lower break frequencies achieved this, but the modified washouts then required reduced motion gains to provide protection from motion travel limits.

Based on average HQRs, the modified set of gains and washouts was slightly better for the hover, vertical translation, pirouette, and slalom tasks. The first three tasks are classified in ADS-33C as precision maneuvers, emphasizing continuous closed-loop control. The slalom has no direct counterpart in ADS-33C, but the requirements on airspeed control for this task were sufficiently tight that it had the characteristics of a precision task as well. Thus, the modified set of motion washout filters was preferred for precision maneuvering. The baseline motion washouts received slightly better average HQRs for the bobup/bobdown and sidestep tasks, both classified as aggressive maneuvers in ADS-33C. Thus, the higher onset accelerations of the baseline set may be preferable for aggressive tasks. The modified set received slightly better ratings for the dash/quickstop, which is also an aggressive maneuver, but a maneuver that uses pitch and surge almost exclusively — two degrees of freedom that were most limited on the VMS. Pilot comments indicate that the pilots were able to discern between the baseline and modified sets. Two of the three evaluation pilots commented specifically on the improved motion cueing with the modified set, while the third pilot complained of unusual motions resulting from reaching software limits.

D. EFFECTS OF TIME DELAYS

The visual delay compensation algorithm employed at Ames Research Center results in effectively removing the time delay between the aircraft response and the generation of a visual image in the cockpit. Interestingly, in the absence of this algorithm the time delay in the visual path is quite close to the effective delay in the pitch and roll angular responses of the VMS motion system, so that the visual and motion systems are most closely in phase when the delay compensation algorithm is off.

Pilot opinion was mixed on the value of the visual delay compensation algorithm, with two pilots generally preferring it off and one preferring it on. The effect of visual delay on average HQRs was generally less than the effect of an equivalent overall transport delay.

Added time delays (either transport delays or a combination of visual and transport delays) produced a rapid degradation in handling qualities. For the best rotorcraft model and baseline motion, added delays (either pure transport or visual-only) of 80 msec resulted in Level 2 average HQRs. An added delay of 383 msec produced Level 3 HQRs.

E. EFFECTS OF BANDWIDTH AND RESPONSE-TYPE

The aircraft model used in this simulation was a linearized representation of a helicopter with no adverse interaxis coupling. The baseline aircraft was designed to be a Rate Response-Type with pitch and roll Bandwidths of 4.0 rad/sec for the ideal model (model attitude/model control position). Measured from stick force input to visual response in the cab, the Bandwidth frequency dropped to 2.8 rad/sec with the visual compensation algorithm on and 2.1 rad/sec with the algorithm off. Response measured from stick force to motion had a Bandwidth of 2.9 rad/sec in pitch and 3.1 rad/sec in roll. This model met the Level 1 requirements of ADS-33C, and it received Level 1 average HQRs moving-base.

A low-Bandwidth Rate Response-Type was evaluated for a limited number of runs. This model was designed to be Level 2 by ADS-33C, and the average HQRs were generally Level 2.

An Attitude Command/Attitude Hold Response-Type, also Level 1 by ADS-33C, received improved HQRs over the Rate systems for the precision tasks of hover, pirouette, and slalom, while the ratings were degraded slightly from the baseline Rate Response-Type for the vertical translation, bobup/bobdown, dash/quickstop, and sidestep tasks. The bobup/bobdown, dash/quickstop, and sidestep are aggressive maneuvers and thus the preference for Rate over Attitude is as expected.

Comparison of the configurations with the pitch and roll Bandwidth requirements of ADS-33C shows very good correlation. If the configurations are compared with the boundaries for UCE > 1, 13 of the 14 configurations meet the requirements. The exception is a case with a single rating of 3 in the Level 2 region.

F. VERIFICATION OF DYNAMICS AND TIME DELAYS

Timing diagrams provided by NASA personnel identified the sources and magnitudes of known time delays in the simulation setup. Three independent forms of frequency-response analysis were used to both verify elements of the timing diagrams and measure unknown time delays in the VMS.

An online frequency-response analysis program was of considerable value during initial checkout and development of the modified motion system. The program had a number of inherent strengths and weaknesses; experience with its use in this simulation supports the continued development and improvement of the software for future applications.

The response characteristics of the VMS motion drive system are best modeled as a combination of a second-order lag and a time delay. A very good approximation is given by a time delay alone. Based on the analysis in this study, the delays in the motion system, measured as the time difference between the math model and cab responses, are approximately 70 msec in pitch and roll, 110 msec in yaw, 160 msec in heave, 170 msec in surge, and 100 msec in sway. Reorientation of the cab on the VMS beam to make the long axis longitudinal and mass and inertia properties of the interchangeable cab itself would be expected to have some effect on these numbers.

G. RECOMMENDATIONS FOR FUTURE INVESTIGATION

This experiment was exploratory in nature, and as a result did not reach any definitive answers on any of the primary objectives. A more thorough simulation, focusing on a few topics, will be necessary to reach any clear consensus. Following are the most critical issues to be resolved:

Motion fidelity/task optimization: The differences between the baseline and modified washout filters evaluated in this simulation support the use of different motion filters for precision vs. aggressive tasks. A systematic variation in motion parameters, defined in terms of phase distortion and gain attenuation (Appendix A), should be performed. The volume of evaluations required can be reduced by using a smaller number of tasks, for example, two precision tasks (e.g., hover and pirouette) and two aggressive tasks (e.g., dash/quickstop and sidestep). It should be possible to determine a range of washouts that is acceptable for each of these tasks.

Motion/visual/Bandwidth effects on perceived handling qualities: This experiment focused on perceived handling qualities for a baseline aircraft model that was designed to be Level 1, and it included only a limited number of runs with a degraded aircraft. Other studies (e.g., Ref. 9) have suggested that there is a nonlinear relationship between actual and perceived handling qualities as both the aircraft Bandwidth and the motion response are degraded. That is, the pilot's perception of the handling qualities of a nominal Level 2 helicopter may be even worse if the motion is degraded as well. In addition, it is conceivable that the pilot's perception of the effects of visual delay may be different when the nominal aircraft has degraded handling qualities. Therefore, a matrix of evaluations should be performed for helicopter models with varying nominal handling qualities (including at least solidly Level 1, solidly Level 2, and on the border between Levels 2 and 3, measured in terms of visual response to cockpit control inputs, and visual compensation included).

At least three different levels of motion should be used. A selected set of combinations should be evaluated with the visual delay compensation removed (based on the current experiment, it is also recommended that the compensation filter be adjusted to remove only 70 msec of delay — to match the effective delays in the pitch and roll cab responses — rather than the 83.3 msec used here).

Motion/visual/Bandwidth effects for different Response-Types: The matrix of evaluations described above should also be investigated for other Response-Types. For example, it is conceivable that the perceived handling qualities of an Attitude Command/Attitude Hold Response-Type, with nominal Bandwidths identical to those of a Rate Response-Type, may be different from those of the Rate system as the motion parameters are changed for both.

Motion utilization estimates: As the motion washouts and gains are varied, the available range of motions (meaning positions, rates, and accelerations) in all axes will vary as well. As these changes are made, it should be possible to define a correlation between what is available and what is actually required. For example, for the nominal Level 1 Rate Response-Type, the perceived handling qualities in the current simulation were best for precision tasks when the modified washouts were employed. These washouts imparted lower accelerations than the baseline set; it may be possible, therefore, to define the minimum acceleration requirements for good perceived handling qualities as long as the corresponding washout requirements (i.e., phase distortion) are not excessive. This is an important measure of the usage and capability requirements of the VMS, and it will give guidance to design and application of other motion systems, most of which will have less travel available. Motion utilization is also a means to quantify piloting differences, such as those found among the pilot population in this experiment.

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APPENDIX A

SELECTION OF MOTION WASHOUT PARAMETERS

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SELECTION OF MOTION WASHOUT PARAMETERS

A. BACKGROUND

The selection of motion system algorithms and command parameters has typically been driven by a combination of the capabilities of the simulation facility and the individual philosophies of the designers. The type of washout design adopted — e.g., linear, adaptive, or optimal — as well as the values of the washouts themselves, has been a matter of engineering judgment following extensive analysis and experimentation. This appendix reviews some of the experiments that have been conducted to investigate the selection of motion washouts.

In the design of any motion system, a fundamental consideration should always be: what type of (and how much) motion does the operator need to accurately convey the proper sense of motion? The motion washouts should always be operator-oriented, that is, they should be based on the characteristics of the human motion-sensing mechanisms. Included in this appendix is a brief overview of the transfer-function dynamics of the vestibular system.

Most motion system experiments to date have used models and tasks related specifically to fixed-wing airplanes. Further, many of the more exhaustive investigations into motion systems have been conducted using simulators with relatively small motion limits to begin with (compared to either actual flight or other moving-base simulators), e.g., the Visual/Motion Simulator at NASA Langley Research Center and the University of Toronto Institute of Aerospace Studies (UTIAS) flight research simulator. It is obviously preferable to conduct such studies on simulators that have a large range of motion displacements available; two of these facilities, the now-retired Flight Simulator for Advanced Aircraft (FSAA) and the Vertical Motion Simulator, both at Ames Research Center, have been utilized only sparingly for these purposes. This appendix shows the results of several experiments conducted on each of them.

Most of the simulation studies have also tended to focus on objective (performance) measures of the effects of motion. While there is obvious merit to this, we are more concerned here with the subjective measures — that is, does the motion system effectively convey the motions to the operator in such a way that the sensation of motion is produced? Unfortunately, the data base for such subjective studies is extremely limited; the available results will be reviewed here.

B. HUMAN VISUAL AND MOTION PERCEPTIONS

Human perceptions of visual and motion stimuli are quite complex and are best handled in volumes on sensory perception, such as Ref. A-1. There has been a great deal of research into the

mechanisms of visual and motion perception; the interest here is on a very narrow subset of this research, dealing with the information necessary for the human operator to perceive visual and motion stimuli. This discussion is therefore limited to transfer-function representations of visual and motion perceptions around the frequencies of interest for most compensatory and pursuit tasks.

1. Visual Operations: The Crossover Model

Because of the interrelationships between visual feedbacks and motion cueing, it is important to understand the basic character of the human operator in closed-loop compensatory and pursuit operations. Later in this appendix we will examine some of the tradeoffs in the time delays between visual and motion systems, and it will be helpful to have some insight into the operator's use of visual information. A much more detailed examination of the subject can be found in Ref. A-2.

The simplest situation to consider is single-input, compensatory tracking in a fixed-base environment, in which the operator is exposed to an error signal and attempts to minimize the error through a manipulator. For a wide range of frequencies around the expected frequencies for closed-loop control, the human operator may be represented by a transfer function, Y_p, given by

$$Y_p = K_p \, e^{-j\omega\tau} \left(\frac{T_L j\omega + 1}{T_I j\omega + 1} \right) e^{-j\alpha/\omega} \, \frac{1}{T_N j\omega + 1}$$

where the term in parentheses is series equalization to improve the open-loop pilot/vehicle dynamics combination near crossover; the delay term due to α derives from low-frequency lag-lead to improve the long-term closed-loop response; and the first-order lag T_N is an approximation for high-frequency neuromuscular actuation.

For the compensatory tracking task, studies show (Ref. A-2) that the operator will adjust his equalization in response to the controlled element, Y_c, to provide an open-loop transfer function, $Y_p Y_c$, of approximately k/s near the region of crossover. In this situation, for frequencies well above the low-frequency delay due to α but well below the neuromuscular mode, the open-loop transfer function may be written (with $j\omega$ replaced by s) as

$$Y_p(s) Y_c(s) \approx \frac{\omega_c e^{-\tau s}}{s}$$

This is the Crossover Model of McRuer and Krendel (Ref. A-2). For most practical operations, the time delay τ is on the order of 0.15-0.25 sec and the crossover frequency ω_c is in the range of 1 to 5 rad/sec.

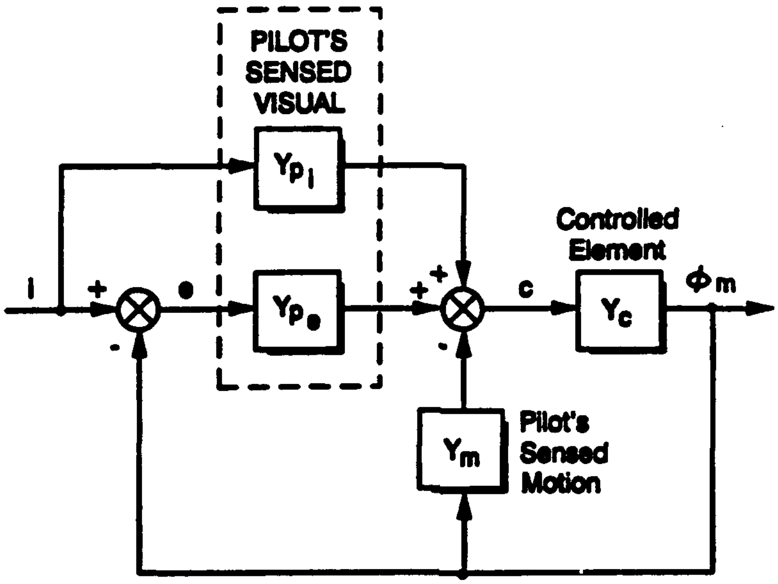
For pursuit-type tasks, where a command (input) is applied in addition to displayed error, the open-loop pilot/vehicle transfer function form is more complicated than just $Y_p Y_c$. In the presence of motion the open-loop transfer function is still more complex. Table A-1 lists the possible combinations of conditions for compensatory and pursuit tasks, both fixed- and moving-base. In the block diagram sketched in Table A-1, the pilot operates on perceived error, e, through an effective transfer function Y_{p_e}; control of the input is through a feedforward path with an effective transfer function Y_{p_i}; and the presence of motion serves to provide a feedback element, Y_m.

2. Motion Perception: The Vestibular System

The sensation of motion in humans is provided by a combination of vestibular and kinesthetic cues (Refs. A-1a and A-1b). The vestibular organs, located in the temporal bones on each side of the head, are referred to as organized systems — so named because their receptors, dynamics, and effects can be defined and evaluated in an organized fashion. Various studies have defined transfer-function forms for the human vestibular system; the forms used here were obtained from Refs. A-3 and A-4, for piloted simulation experiments. While the following addresses the vestibular responses only, it is not meant to imply that the responses of the kinesthetic receptors are not important. The vestibular system consists of the semicircular canals and the otoliths. The semicircular canals provide our sensation of angular acceleration, and the otoliths are linear accelerometers for vertical (the utricles) and lateral (the saccules) accelerations. Linear transfer-function representations exist only for the semicircular canals and utricles.

By contrast, the kinesthetic receptors are distributed throughout the body in muscles, skin reactions, tendons, etc. Motion cueing information is provided by the muscles of the head and neck, and by body pressures such as those imparted on the ischial tuberosities (pelvic extensions in the buttocks). Research on these effectors is very limited; available models (e.g., Ref. A-5) suggest that the importance to motion sensing of these effectors may be as great as those of the vestibular system. The models also imply much higher effective bandwidths, with sensitivities up to as high as 2 Hertz. Little quantitative data exist to separate these elements from the vestibular system, however, and in the absence of such data the dynamics of the vestibular system are at least considered to be most representative of human motion sensing for our purposes.

TABLE A-1. HUMAN OPERATOR/CONTROLLED ELEMENT TRANSFER FUNCTION FORMS



Conditions for Task, Motion	Open-Loop T.F., ϕ_m/e	Closed-Loop T.F., ϕ_m/i
1. Compensatory Tracking: Fixed Base: $Y_{p_i} = Y_m = 0$	$Y_{p_e} Y_c$	$\frac{Y_{p_e} Y_c}{1 + Y_{p_e} Y_c}$
2. Pursuit, Fixed Base: $Y_m = 0$	$\frac{Y_c(Y_{p_e} + Y_{p_i})}{1 - Y_c Y_{p_i}}$	$\frac{Y_c(Y_{p_e} + Y_{p_i})}{1 + Y_c Y_{p_e}}$
3. Compensatory, Moving Base: $Y_{p_i} = 0$	$\frac{Y_{p_e} Y_c}{1 + Y_c Y_m}$	$\frac{Y_{p_e} Y_c}{1 + Y_c(Y_{p_e} + Y_m)}$
4. Pursuit, Moving Base	$\frac{Y_c(Y_{p_e} + Y_{p_i})}{1 + Y_c(Y_m - Y_{p_i})}$	$\frac{Y_c(Y_{p_e} + Y_{p_i})}{1 + Y_c(Y_{p_e} + Y_m)}$

a. The Semicircular Canals

While the semicircular canals are responsive to angular accelerations, their dynamic characteristics are such that over the range of frequencies normally used in manual control they can be considered as rate gyros to provide the operator with a subjective impression of angular velocity. The model for the semicircular canal path can be represented as shown in Fig. A-1a (Ref. A-4). At very low frequencies (below the break frequency $1/T_1$ in Fig. A-1a), the sensors of the semicircular canals are effectively washed out, and at high frequencies (above $1/T_2$) the sensors are attenuated. There is, therefore, a region of frequencies between $1/T_1$ and $1/T_2$ where subjective angular velocity accurately follows actual angular velocity. The thresholds for angular velocity detection are quite small, from about 1.1 deg/sec for yaw to 3.2 deg/sec for roll. Pilot equalization is of a form comparable to the visual-only model described above, with adjustable gain and lead and a time delay on the order of 0.2 sec.

The frequency response of subjective/actual angular velocity is shown in Fig. A-2a for roll rate (the responses for pitch and yaw are very similar, the only difference being the low-frequency mode $1/T_1$, which varies between 0.125 and 0.189 rad/sec). This figure shows that for the region between $1/T_1$ and $1/T_2$, the operator's subjective sense of angular velocity almost exactly represents the actual velocity, with unity magnitude and minimal phase distortion.

b. The Utricles

The utricles are linear accelerometers that, like conventional accelerometers, respond not to inertial acceleration but to the total applied specific force. For example, on the ground the utricles respond to tilting the head relative to the gravity vector just as an accelerometer attached to the head would.

A model for the utricular path is illustrated in Fig. A-1b (Ref. A-4). The threshold on sensed acceleration is so small, on the order of 0.1 g or less, that it can be ignored. Pilot equalization is of a form similar to that for the visual model, with a gain, lead/lag, and time delay. The frequency response for this model, for subjective/actual linear acceleration, is shown in Fig. A-2b. There is some attenuation of the sensation at low frequencies, and a rolloff above $1/T_6$ (Fig. A-1b). The phase difference between subjective and actual accelerations is less than ±30 deg for a range of frequencies from 0.26 to 1.1 rad/sec.

c. Implications for Motion System Design

Using the frequency responses of Fig. A-2 as a guide, it seems reasonable to require that simulation motion washouts in angular rate should induce no significant phase distortions higher in

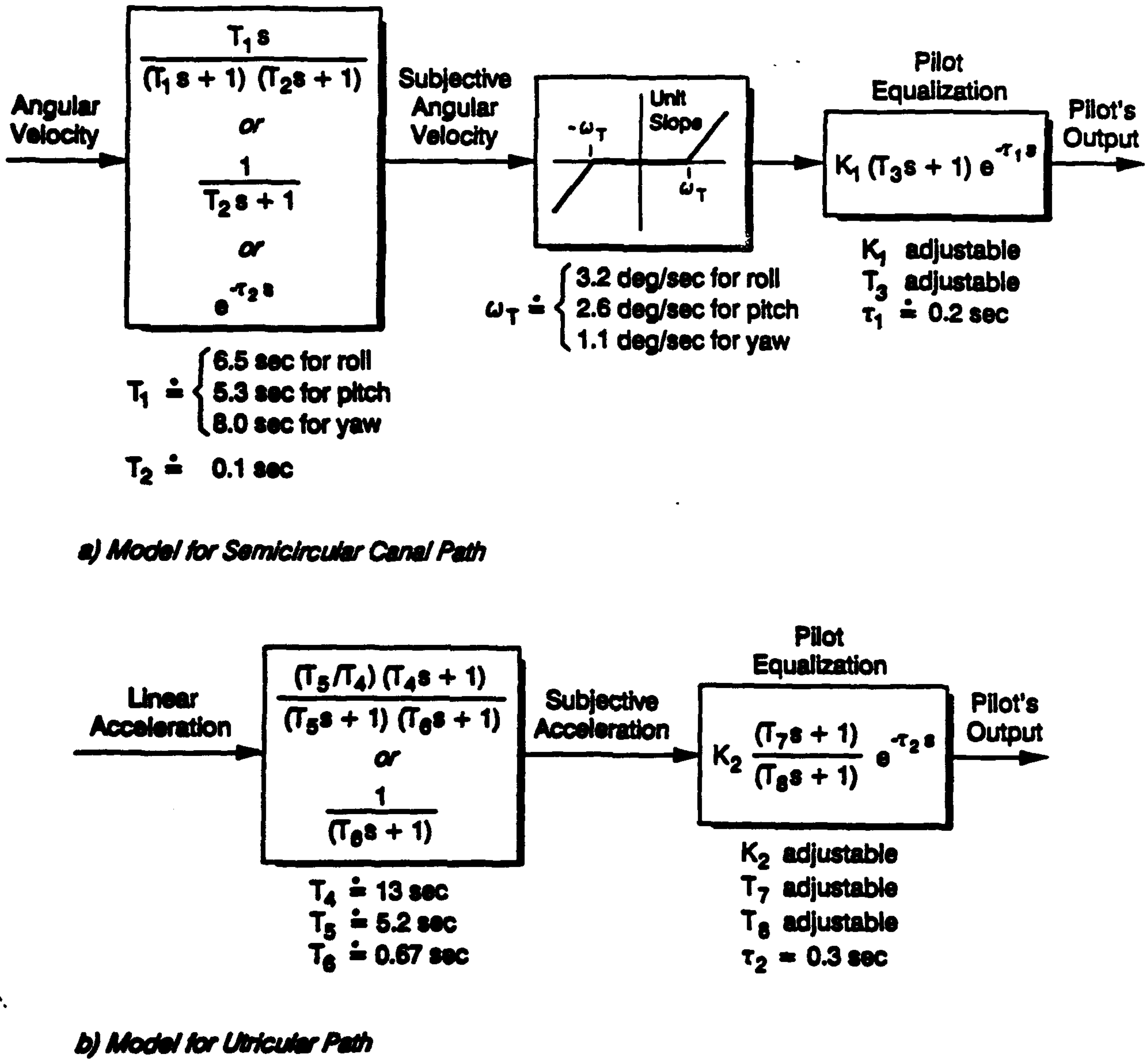
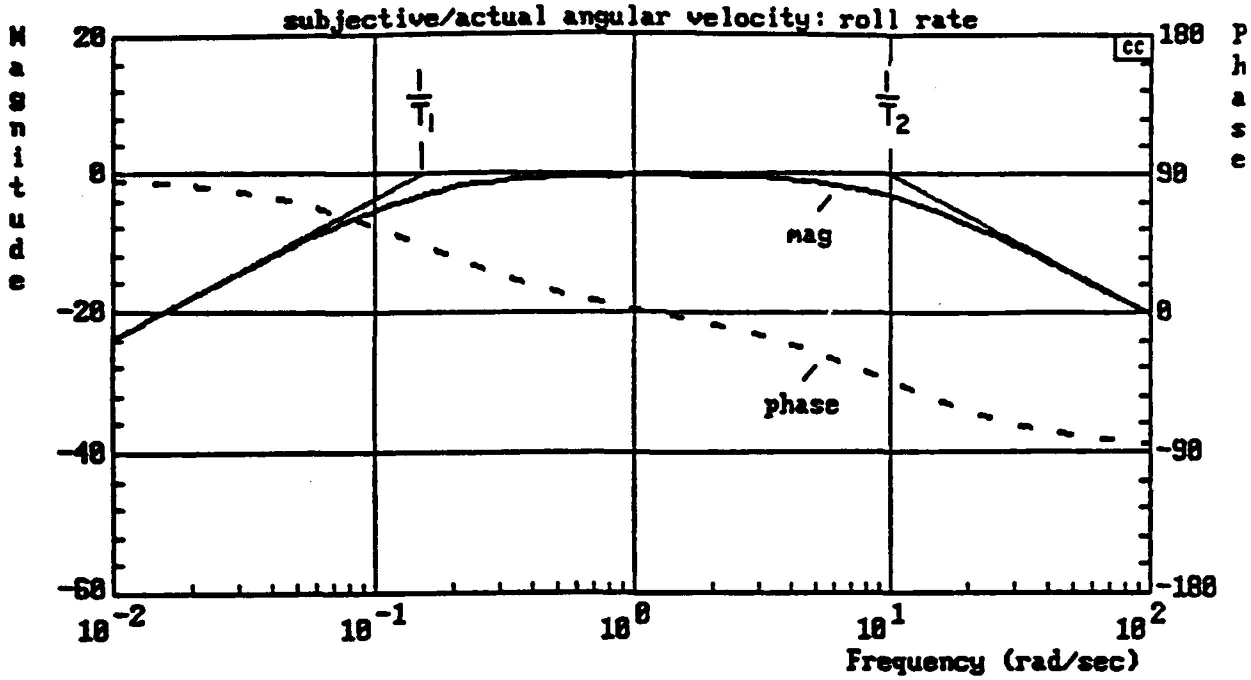
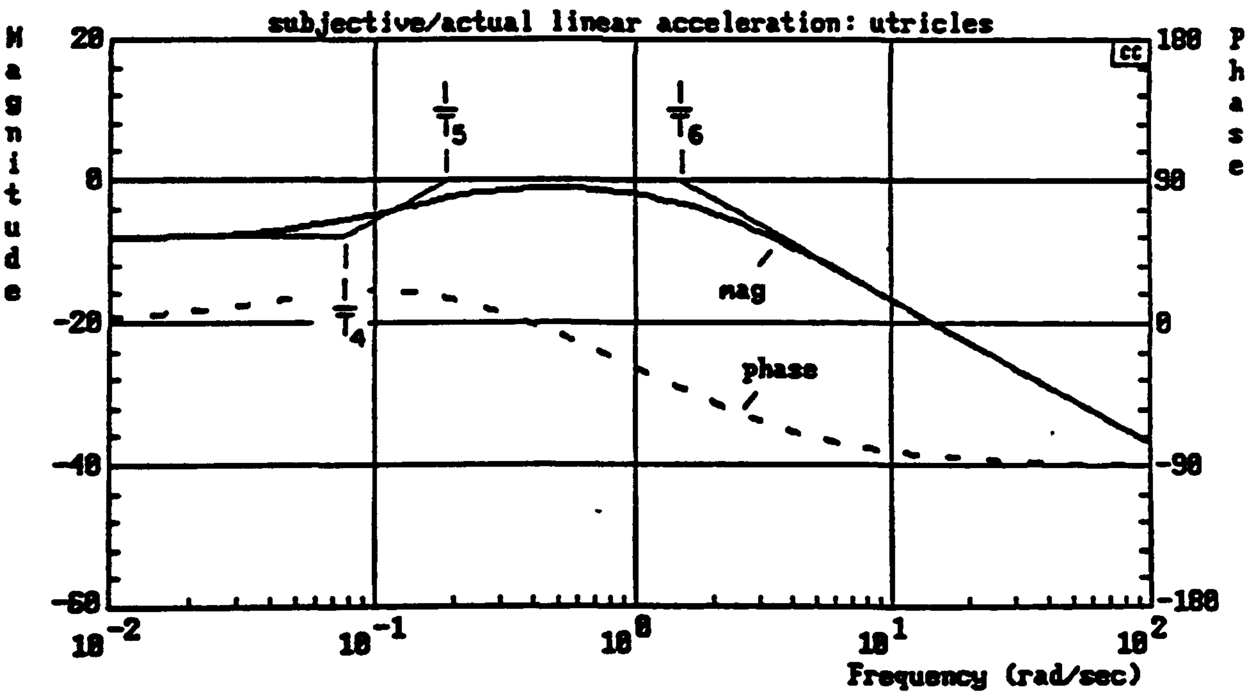


Figure A-1. Simple Models for the Vestibular System



a) Subjective/Actual Angular Velocity (Roll Rate Shown)



b) Subjective/Actual Linear Acceleration

Figure A-2. Frequency Responses of the Vestibular System

frequency than about $1/T_1$, i.e., somewhere around 0.2 rad/sec. Below this frequency, the pilot would not be expected to detect the unnatural operation of the washout, which otherwise presents a false cue to the semicircular canals. In addition, there should be no significant delays or other sources of phase rolloff at frequencies below about $1/T_2$, i.e., 10 rad/sec.

For replication of vertical acceleration motions, the utricular path response of Fig. A-2b suggests minimal phase distortions due to washouts above about $1/T_5$, on the order of 0.2 rad/sec, with no significant lags or delays below about $1/T_6$, or 1.5 rad/sec.

It must be reiterated that these proposed guides apply only to the vestibular system and do not properly account for the very significant effects of the kinesthetic senses. Effects such as muscles tightening in the neck during angular motions, and compression into the seat (or lightening in the seat) during vertical motions, will also play an important role. To be safe, a reasonable range of frequencies over which phase distortion should be minimized (motion/actual less than ±30 deg, based on Ref. A-6) is 0.2-10 rad/sec in all directions. As is shown below, first-order washouts in roll with break frequencies of 0.4 to 0.5 rad/sec have been used in flight simulations with no apparent negative comments from the pilots, so it may be possible to relax the lower limit somewhat.

C. STUDIES OF MOTION WASHOUT REQUIREMENTS

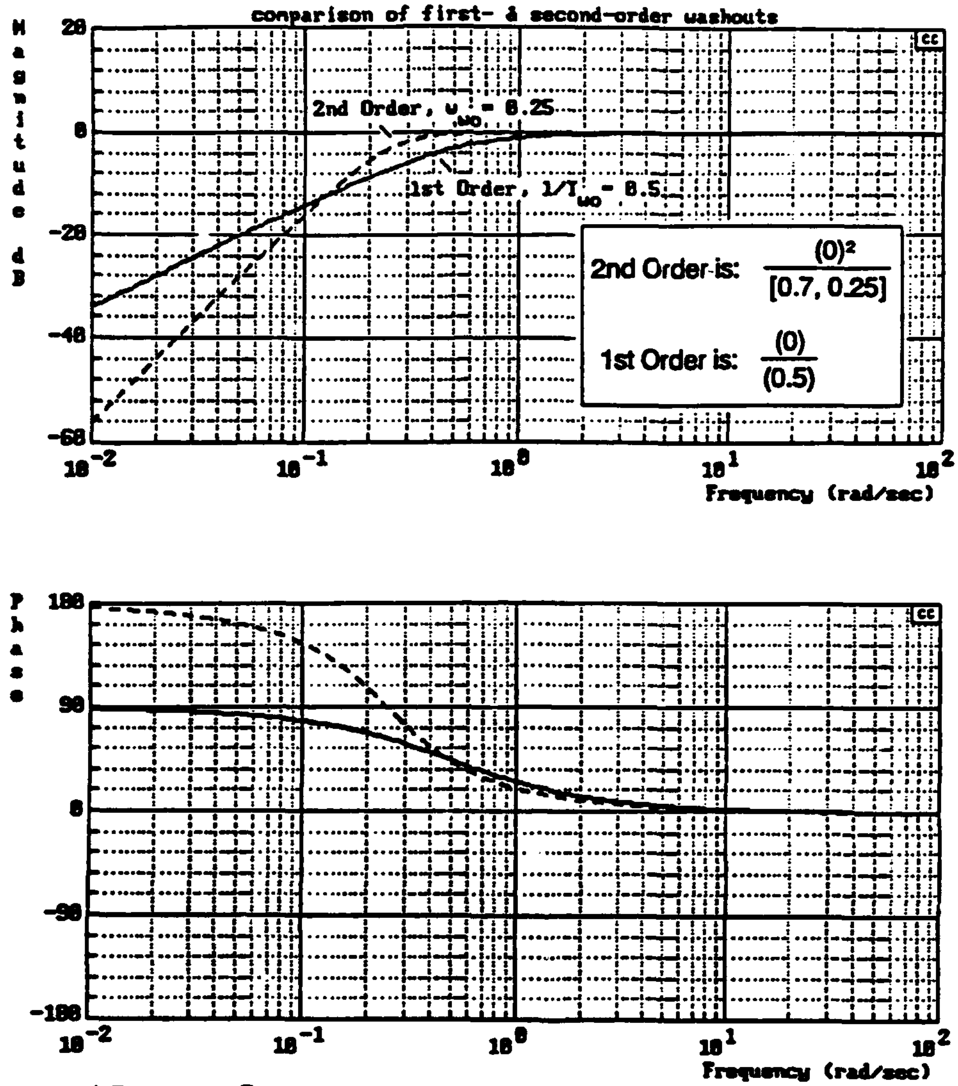
Despite the intense interest in motion washout designs, and the obvious need for some form of quantitative guidelines for setting the parameters in classical washouts, there have been very few experiments in this area and little published data is available. Such studies would clearly involve the variation of a wide range of parameters, including washout gains and break frequencies in both rotational and linear dimensions, but also should include the effects of secondary motions — such as residual tilt or resolution of the g vector in turns — to produce a catalog of acceptable values. In addition, such studies would be highly dependent on the capabilities of the subject simulator: heave or sway requirements for the NASA Ames Vertical Motion Simulator are vastly different from those of the NASA Langley Visual/Motion Simulator, for example.

In reading the following, it is important to consider in each study the particular simulator used and its physical characteristics. The results of any motion-system experiment will, by definition, be strongly affected by the facility and its capabilities. In addition, the aircraft type, missions, and specific tasks will have bearing on the conclusions. In most studies — especially in those where objective pilot describing function measurements were made — the task consisted of compensatory tracking in one or more axes. This task clearly requires less overall physical maneuvering space than out-the-window pursuit tasks, e.g., air combat, landing, etc. The motion system parameters that were best for compensatory tasks may not be suitable for other mission elements.

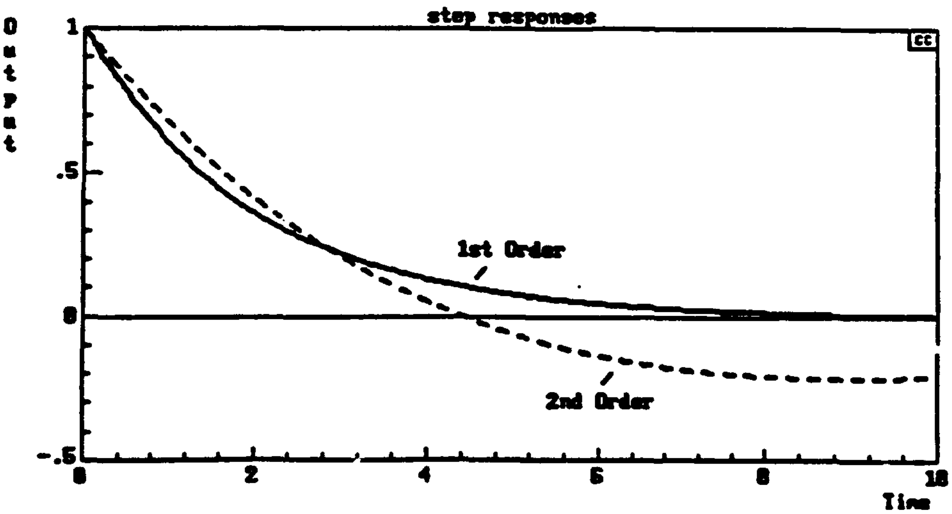
The experiments generally fall into three categories: 1) Objective measures of motion performance. The experiments described here were either partially or totally devoted to measurements of pilot performance, e.g., rms errors, control activity, describing functions, etc. Such data tell us the quantitative consequences of changes in motion washouts, but they are not useful in determining the impact of these changes on the pilots' opinions. 2) Subjective measures of motion performance. In these studies, the pilots were asked to assess, with different rating scales and methods, one or more of the features of the motion system under consideration. From a handling qualities standpoint, this is more interesting than the objective data, since it tells us how important the motion cues are on the pilots' opinions. 3) Visual/motion tradeoff studies. In these experiments either visual, or visual and motion, variations were performed. Measures of performance for this set of data consist of both objective and subjective results.

All of the studies described here used linear, fixed-parameter ("classical") washout schemes, as is in use on the VMS. The filters employed in these experiments were both first- and second-order. A comparison of the frequency and time responses of such washouts is shown by an example in Fig. A-3, where a first-order washout with inverse time constant $1/T = 0.5$ rad/sec is compared with a second-order with damping of 0.7 and frequency of 0.25 rad/sec. Both filters produce about the same phase distortion above 0.5 rad/sec. The differences are at the low frequencies, since the second-order washout introduces 180 deg of phase lead compared to 90 deg for the first-order. The time responses illustrate the benefit of the second-order washout: the signal returns to zero by slightly more than four seconds, while for the first-order there is a continuing standoff error until about eight seconds. The initial slope of the time response for the second-order is also lower, indicating a lower acceleration in the return signal. On the other hand, the second-order washout actually commands a return <u>through</u> zero and therefore requires either a reduction in gain, a threshold for removing the signal, or acceptance of some undesirable residual cab motion.

The classical washout scheme is most common in simulators with relatively large displacements in one or more axes, including the NASA Ames Vertical Motion Simulator (VMS, Ref. A-7), the now-retired Ames Flight Simulator for Advanced Aircraft (FSAA, Ref. A-6), and the Air Force's Large Amplitude Multimode Aerospace Research Simulator (LAMARS, Ref. A-8). This is the easiest scheme to apply, since all parameters of the motion system are fixed in value. In addition, the number of equations required is typically low (Ref. A-11), so computation time is faster than with other methods. The major disadvantage is that the gains and washouts must be set based upon the largest expected motions for a given task or experiment (unless occasional motion limit trips can be tolerated), resulting in reduced motions for more benign tasks.



a) Frequency Responses



b) Time Responses (unit step input)

Figure A-3. Comparison of First- and Second-Order Washouts

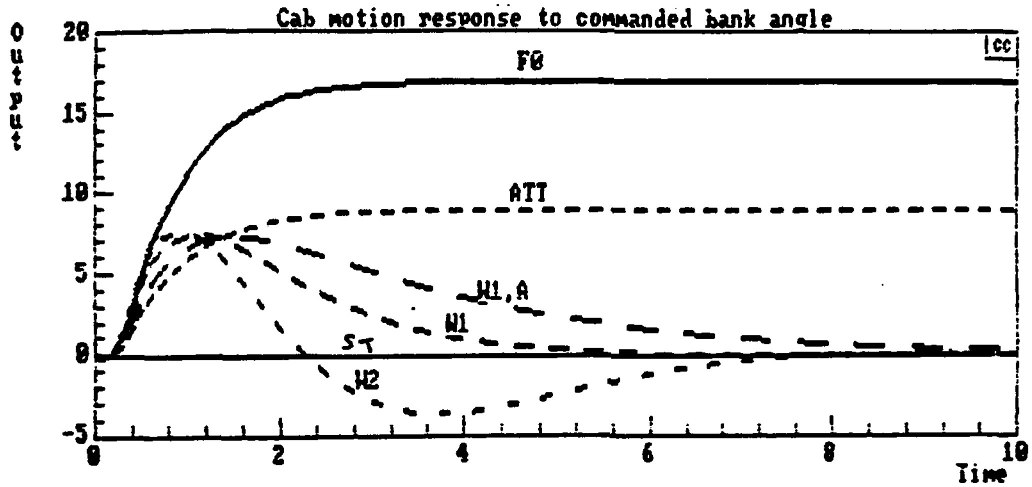
Other washout schemes employed include optimal-control-design washouts, e.g., Refs. A-9, A-10, and A-11, and coordinated adaptive, e.g., Refs. A-10 through A-13. Data for these schemes are not described here since neither scheme is used on the VMS.

1. Rotational Motion Scaling and Washouts

Since, for aircraft, the rotational and translational degrees of freedom are connected (especially for coordinated turning flight, i.e., where lateral acceleration is zero), it is difficult to separately specify the gains and washout break frequencies for these degrees of freedom. We can, however, glean some information from several experiments conducted on simulators with no translation at all. Such simulators generally pitch and roll (or, depending upon orientation, pitch and yaw) about the cab. There is experimental evidence (e.g., Ref. A-14) that for a purely IFR, compensatory task such as hovering in turbulence, pilots actually prefer angular-only motion. This is apparently due to the much greater importance of the g-vector tilt cue for determining absolute vertical compared to the translational acceleration cue provided by the otoliths.

Reference A-13 reports on a study of motion washouts and gains on a two-degree-of-freedom (pitch and roll) simulator, the Dynamic Environmental Simulator, at the Air Force Aerospace Medical Research Laboratory at Wright-Patterson AFB, OH. Only the roll degree of freedom was used for this study; subjects tracked a target display on an attitude indicator, with turbulence injected as well. Figure A-4b lists the transfer functions for the motion filters evaluated, ranging from no filtering (F0) to attenuated motion (ATT) and purely static (ST) cases. As the time histories in Fig. A-4a show, all of the filters except F0 and ST effectively reduced the peak angular travel to about one-half of full commanded travel. The second-order washout W2 most faithfully reproduced the initial response, but then returned to (and through) center position most rapidly. Not surprisingly, this study found the full-motion F0 and attenuated-motion ATT systems to be best in terms of recovered motions and subject preference. The static case was clearly worst, while the second-order washout — with an unusually high break frequency of 0.85 rad/sec — was both confusing to the pilots and poor in recovering angular rates. The first-order washout with attenuation, W1,A, was preferred overall. This washout had a break frequency of 0.4 rad/sec and gain of 0.7. (This filter exhibits 45 deg of phase lead at 0.4 rad/sec, and the 30-deg-phase frequency, the criterion for our hypothesis about human motion sensing discussed above, is at 0.69 rad/sec). The authors of Ref. A-13 recommend, for first-order washouts on roll-only simulators, an attenuation factor of 0.5-0.7 and break frequency of 0.3-0.5 rad/sec.

In terms of tracking performance, the results of the simulation of Ref. A-15 concur with the attenuation factor from Ref. A-13. The Ref. A-15 study was also conducted on a two-degree-of-freedom (either pitch and roll or pitch and yaw) simulator. Two-axis compensatory tracking was



a) Bank Angle Responses to a Unit Control Input

$$\text{FO:} \quad \frac{\phi_M}{\phi} = 1.0$$

$$\text{W2:} \quad \frac{\phi_M}{\phi} = \frac{1.2s^2}{[s^2 + 2(0.7)(0.85)s + (0.85)^2]}$$

$$\text{W1:} \quad \frac{\phi_M}{\phi} = \frac{1.0s}{s + 1.0}$$

$$\text{W1,A:} \quad \frac{\phi_M}{\phi} = \frac{0.7s}{s + 0.4}$$

$$\text{ATT:} \quad \frac{\phi_M}{\phi} = 0.53$$

$$\text{ST:} \quad \frac{\phi_M}{\phi} = 0$$

$$\text{Aircraft + Simulator:} \quad \frac{p}{F_{as}} = \frac{-658.24(s - 25)}{s(s + 1.6)(s + 5)[s^2 + 2(0.3)(11)s + (11)^2]}$$

b) Transfer Functions for Controlled Element and Washouts

Figure A-4. Motion Filters Evaluated on Roll-Only Tracking Experiment of Ref. A-14

conducted for varying levels of gain with no motion washouts. Normalized mean square tracking errors in both pitch and yaw for the no-motion case were well above those for full motion, with a consistent improvement in tracking as motion amplitude was increased. Negligible differences in tracking error were found for increases above about 50 percent of full motion.

Reference A-16 reports on a two-degree-of-freedom (pitch and roll) evaluation of second-order washouts on a hexapod-type simulator. This experiment again involved tracking of artificial disturbances, generated by a sum-of-sines forcing function in pitch and roll, with washout filter damping of unity and break frequencies of 0.1, 0.25, and 0.5 rad/sec (fixed-base evaluations were included for reference). The gain on roll was unity as well; measured dynamics in Ref. A-16 indicate that the simulator's pitch response was amplified by about 1.4 at high frequencies. Total displacements on the simulator were limited, with only about ±20 deg maximum from center in either pitch or roll (strut throw of ±11 in.). Compression of struts to transmit motions in one axis would further limit the available travel in the other axis. The aircraft model was based on a DC-9 in landing configuration and therefore was relatively slow in responding. As a result of these factors, the overall observations should be taken to represent a fairly low-bandwidth operation.

The only data in Ref. A-16 consist of quantitative measures of pilot describing functions (gain, effective lead time constant, and effective time delay) and performance measures (rms errors). Very little effect of washout break frequency was found in going from 0.1 to 0.25 to 0.5 rad/sec; there was a slight tendency for lowered pilot gain and increased lead, but no consistent trends were found. There was, however, a large difference between the moving-base cases and the fixed-base situation, where overall pilot performance was considerably degraded. Based on these results, Ref. A-16 suggests that second-order rotational washouts with break frequencies as high as 0.5 rad/sec (for the specific filters and effective lags of the simulator, this corresponded to a 30 deg phase distortion frequency of 1.4 rad/sec) will not cause any substantial change in pilot performance. Pilot effort was addressed in Ref. A-16 by asking the pilots to rate their effort required for pitch and roll control. These ratings show some increase in effort as washout is increased, but no pilot complained of discomfort or disorientation, even for the highest washout (perhaps, again, influenced by the limited travel available).

2. Linear Acceleration Scaling and Washouts

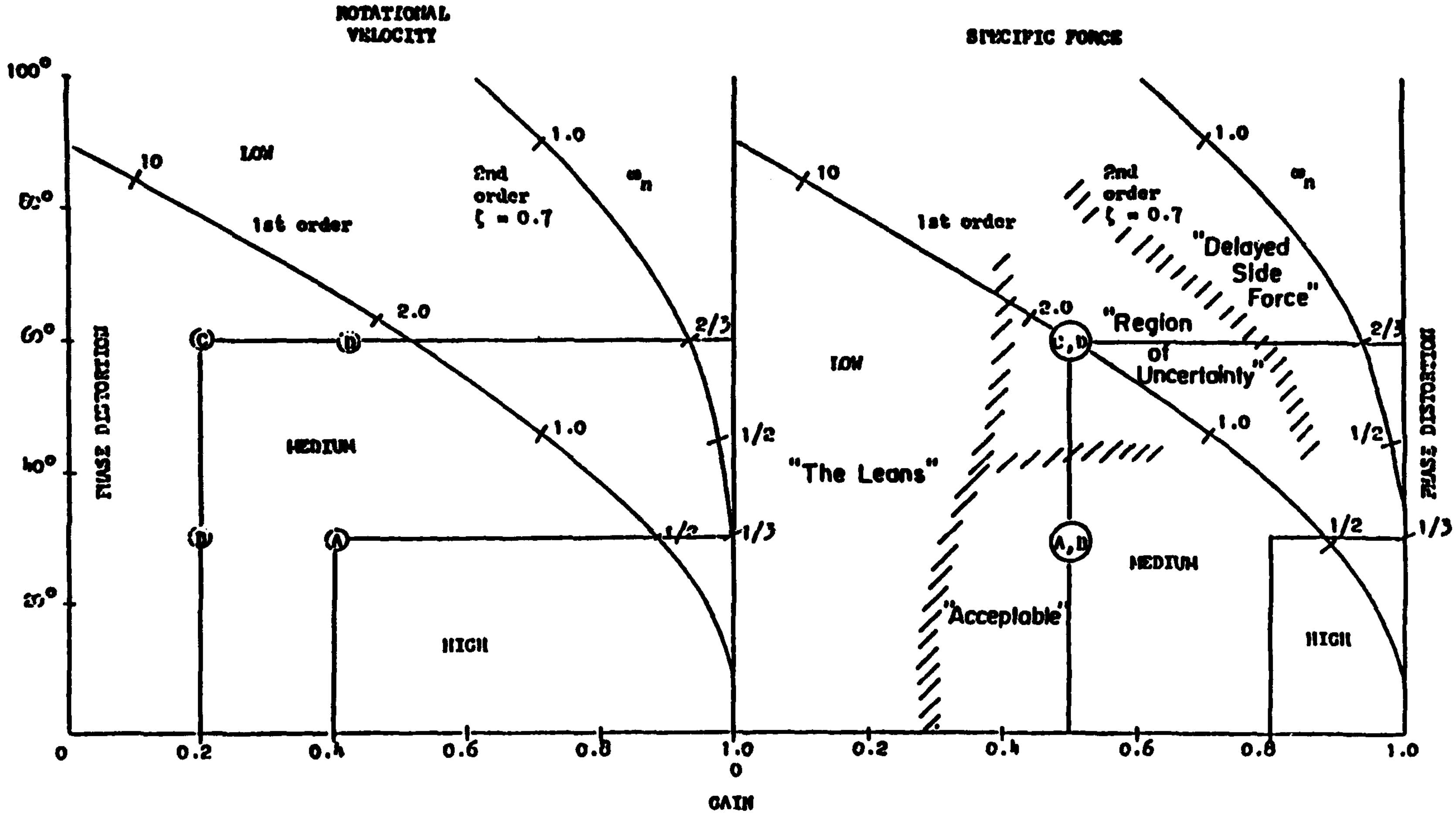
For the evaluation of linear acceleration motion cueing, it is clearly necessary to have a facility capable of producing substantial accelerations to begin with. This eliminates a considerable number of simulators; of currently operational simulators, only two have reasonably large translational degrees of freedom: the VMS at NASA Ames Research Center, and the Large-Amplitude Multimode Aerospace Research Simulator (LAMARS) at Wright-Patterson AFB, OH. The VMS has a set of

interchangeable cabs, mounted on a gimbal for rotational motions. The entire cab-plus-gimbal assembly is then mounted on a beam with ±30 ft of vertical and ±20 ft of horizontal travel. Depending upon cab orientation, the horizontal travel can be used to provide either longitudinal or lateral displacements; travel in the other direction is limited to ±4 ft. The LAMARS is a fighter-type cockpit mounted in a cab on a 20-ft cantilevered beam that produces five degrees of freedom. Travel vertically and horizontally is limited at ±10 ft.

Other simulators that have been decommissioned, but that produced useful data, include the Flight Simulator for Advanced Aircraft (FSAA), the Six-Degree-of-Freedom (or S.01) simulator, and the Height Control Test Apparatus (HCTA), all of which were at NASA Ames. Some data may be obtained (with great care and consideration) from other valid, but limited-travel, simulators, such as the Visual/Motion Simulator (VMS) at NASA Langley, and the UTIAS research simulator at the University of Toronto. Data from these hexapod-type cabs will be heavily influenced by the fact that the best possible acceleration information is still mitigated since the resulting velocities and displacements must be removed very quickly to avoid hitting software and hardware limits. In addition, transmission of linear accelerations will be affected by strut compression or extension required to transmit rotational accelerations (i.e., if most of the travel is already commanded for banking, little will be available for a vertical acceleration command).

Reference A-17 contains the results of a very brief (one-day) evaluation on the FSAA of roll/sway requirements for helicopter simulation. In addition, some tentative design criteria are given in Ref. A-17 for specifying the motion fidelity for simulators in terms of phase distortion and gain measured at a frequency of 1 rad/sec (selected because this is the approximate frequency where motion sensing by the semicircular canals is best). These criteria are shown in Fig. A-5 (along with recommendations from another source, discussed below). It is important to recognize that the gain plotted on Fig. A-5 is the gain at one radian per second, not the scaling factor for the washout filter. Drawn on Fig. A-5 are the characteristics of first- and second-order washouts, with unity motion scaling gain, as a function of break frequency. Note, for example, that a first-order washout with a break frequency of 0.5 rad/sec (suggested above as an approximate reasonable limit) is just at the edge of the "HIGH" motion fidelity region for both rotational velocity and specific force.

The points labeled A, B, C, and D were evaluated by one pilot for precision hover and 60-kt S-turn tasks. The pilot was asked to rate his impressions of the motion cues relative to the visual scene. An additional four cases were flown at point D, with reduced sway motion gains from the initial 1.0 to 0.6, 0.4, 0.2, and 0. This effectively reduced the travel of the simulator laterally; for unity gain the recovered side force is due to lateral translation as it is in actual flight, while zero sway gain produces a purely rolling simulator in which the recovered side force transmitted to the pilot is due entirely



HIGH: Motion sensations are close to those of visual flight
MEDIUM: Motion sensation differences are noticeable but not objectionable
LOW: Differences are noticeable and objectionable, loss of performance, disorientation

Figure A-5. Motion Fidelity Versus Phase Distortion and Gain at 1 rad/sec (from Ref. A-17; Shaded Regions Defined in Quotes are Adapted from Ref. A-13; Points A,B,C,D are Described in Text)

to tilting the cab. The results of this brief experiment are summarized in Table A-2. The pilot comments generally support the division of regions on Fig. A-5.

A roll-sway experiment was conducted on the LAMARS simulator to investigate pilot performance and opinion for target tracking in the presence of disturbances. The results of this study are documented fully in Ref. A-13 and in more concise form in Ref. A-8. The fixed-wing aircraft model was designed to provide perfect turn coordination ($a_y = 0$) flight, and the roll motions of the LAMARS were washed out through a first-order filter with unity gain and a break frequency of 0.4 rad/sec.

TABLE A-2. SUMMARY OF FSAA TEST RESULTS
(From Ref. A-17)

Condition	K_ϕ	ω_ϕ (rad/sec)	$K_{\phi Y}$	Maximum Lateral Travel (ft)	Pilot Comment
A	0.4	0.33	1.0	± 36*	Acceptable rolling impression with coordinated sensation. Limits felt.
B	0.2	0.33	1.0	± 36*	Acceptable rolling impression with coordinated sensation. Limits felt.
C	0.2	0.67	1.0	± 20	Illusion of motion appears subdued but is still acceptable. Good turn coordination.
D	0.4	0.67	1.0	± 26	Acceptable rolling impression. Turn coordination and side force buildup in slips is felt.
D1	0.4	0.67	0.6	± 16	Not much different from Case D.
D2	0.4	0.67	0.4	± 12	Feels more subdued and can notice "jerkiness."
D3	0.4	0.67	0.2		Poor turn coordination: Feels like lateral turbulence.
D4	0.4	0.67	0		Noticeably poor turn coordination that is difficult to correct.

* Lateral axis encountering limits of ± 36 ft.

The simulation setup and results from Ref. A-13 are summarized in Fig. A-6. The results are shown graphically on a crossplot of sway motion scaling factor, K_y, versus washout frequency, ω_y (washout damping was constant at 0.7). A region of acceptable sway motions was identified based on pilot comments; this region is actually much larger than shown, including much of the area that was not testable due to the travel limits on the LAMARS. The various regions on Fig. A-6 have been reinterpreted in terms of gain and phase distortion at 1 rad/sec, consistent with Ref. A-17, and were included as hatched areas on the right side of Fig. A-5 (the roll washout lies in the high-motion-fidelity region for rotational velocity). The acceptable region of Fig. A-6 roughly corresponds to the medium- and high-fidelity areas in Fig. A-5. The low-fidelity region in Fig. A-5 is further identified by the Fig. A-6 results as being due to either delayed side forces (high phase distortion due to rapid washout) and a condition known as "the leans" (low translational gain resulting in almost pure rotation and a feeling of leaning in the seat straps during turns).

The Ames Height Control Test Apparatus was a simulator with only one degree of freedom, vertical, with displacements of ±40 ft. The experiment of Ref. A-18 investigated the importance of acceleration cues for visual approach and landing of a large transport aircraft. The only direct feedback to the pilots of touchdown performance was the combination of visual and motion cues. Three configurations were evaluated; one represented a stable airplane with good flying qualities, while the other two had degraded dynamics including instabilities. Second-order washouts with unity gain were used for vertical motion; damping was constant at 0.7 while frequency was varied from 0.2 to 1.4 rad/sec. The evaluations were also performed fixed-base. The only performance information reported in Ref. A-18 is aircraft sink rate at touchdown.

Figure A-7 shows the results of the Ref. A-18 experiment. The sink rates in Fig. A-7 represent averages from four pilots and several landings following training runs; thus the changes in sink rate are expected to be due primarily to the feedback provided to the pilots from earlier runs. For the good airplane (Configuration 1) there was little change in sink rate as washout frequency was varied, including the no-motion case. For the two bad configurations (Configurations 2 and 3), however, there is both an incremental degradation from the good airplane and a rapid deterioration in sink rate above a break frequency of about 0.5 rad/sec. These data suggest that 1) the influence of washout frequency is much more important when the dynamics of the vehicle under consideration are bad, and 2) the break frequency for second-order washouts should not exceed 0.3 to 0.5 rad/sec.

Similar results were obtained in a simulation on the Ames VMS and reported in Ref. A-7. A model of the XV-15 tilt-rotor aircraft was flown through nap-of-the-earth and bobup tasks by four pilots. In this case the vertical-axis washout frequency was set at 0.2, 0.8, and 1.8 rad/sec for a second-order washout (unity gain, damping ratio of 0.7) and the vertical-axis (collective control) handling

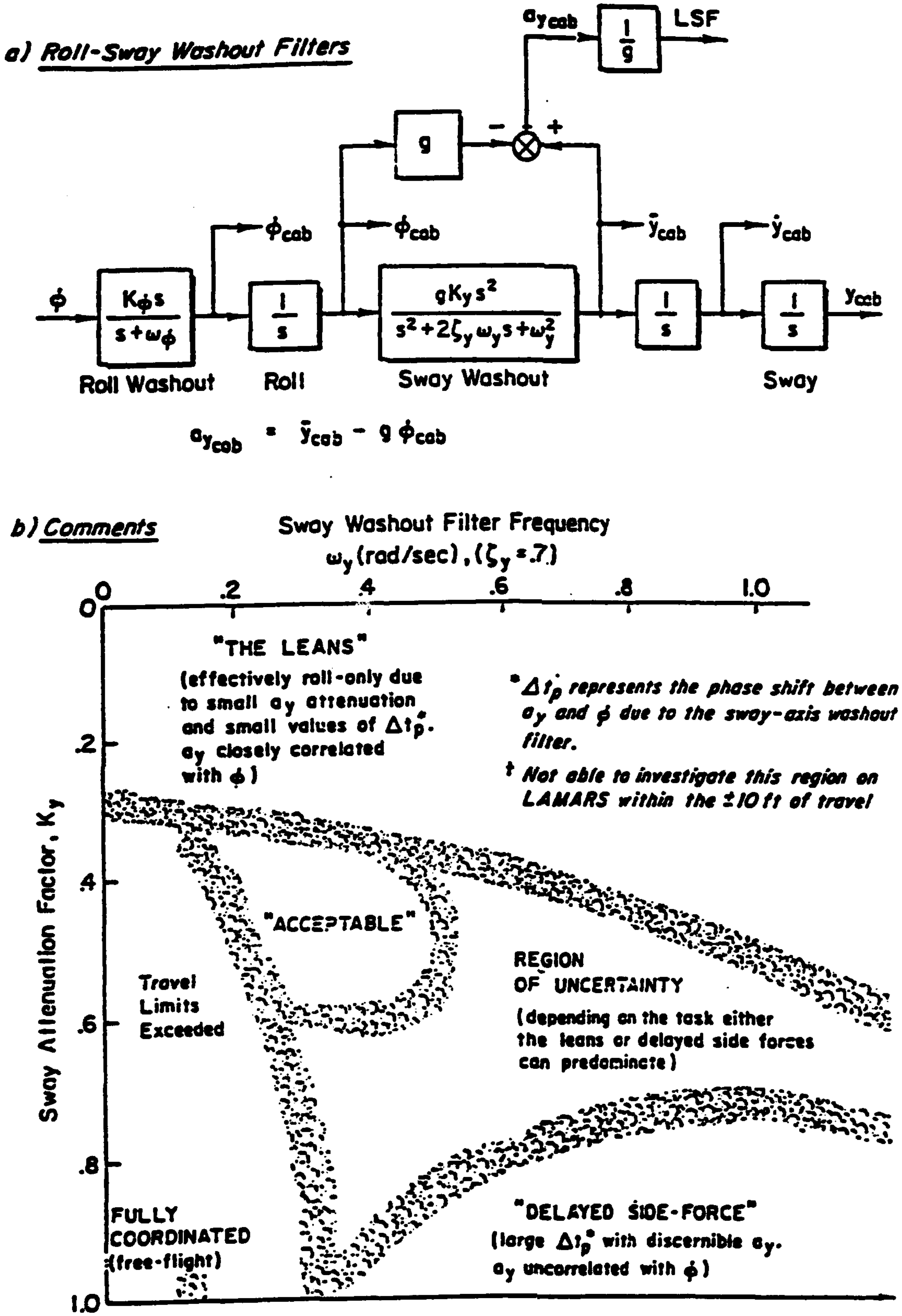


Figure A-6. Correlations of Comments vs. ω_y and K_y for Roll-Sway Coordination Study (Ref. A-13)

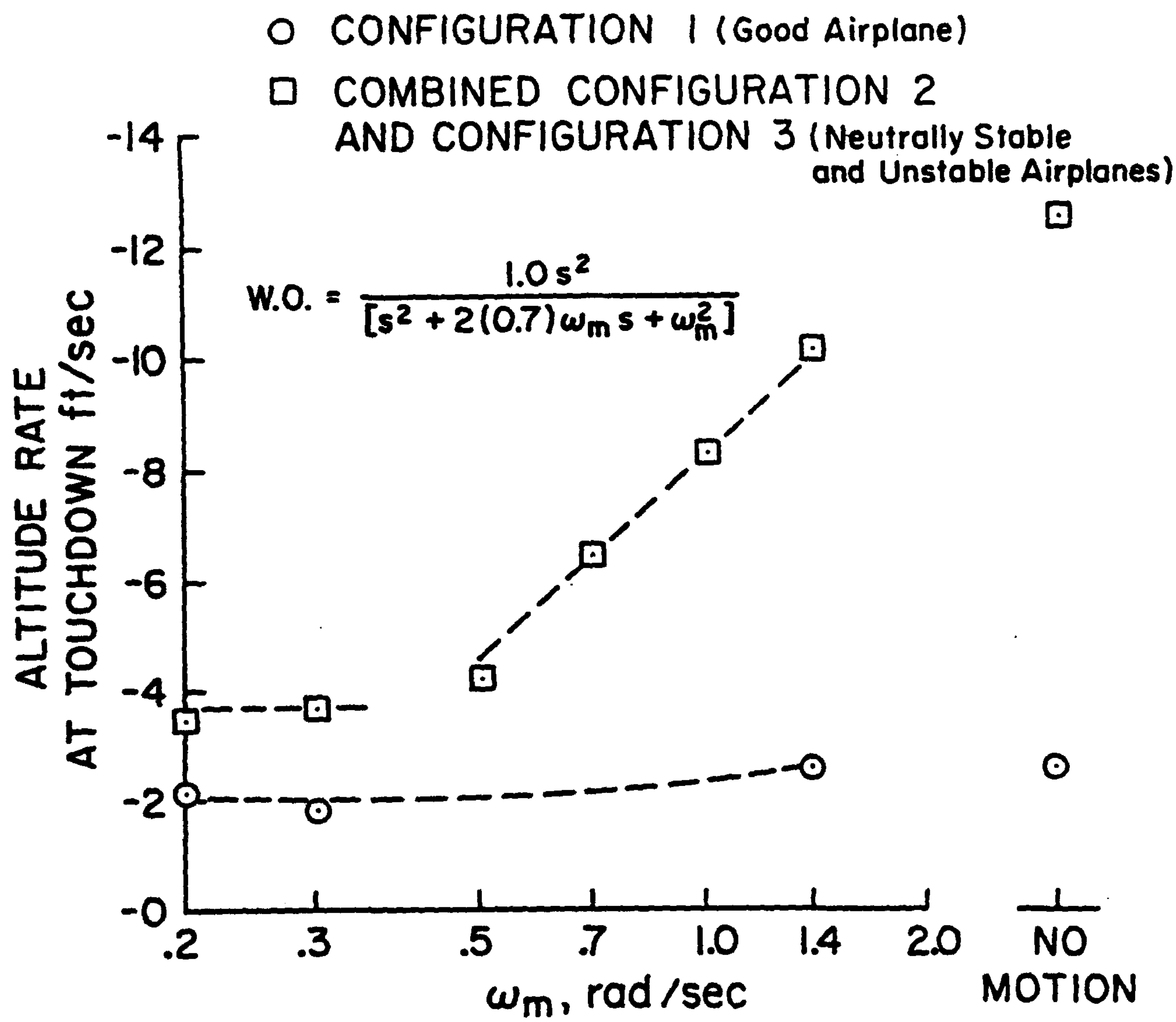


Figure A-7. Effects of Washout Filter Natural Frequency, ω_m, on Landing Performance (From Ref. A-18)

qualities of the XV-15 model were degraded. Results consist of Cooper-Harper Handling Qualities Ratings (HQRs, Ref. A-19), as shown in Fig. A-8. This figure shows that the ratings were relatively insensitive to washout frequency for the nominal XV-15 (circle symbols). As the collective response is degraded at any value of washout, the expected degradation in ratings occurs. This degradation, however, is not uniform, i.e., the relative degradation is much greater at a washout frequency of 1.8 rad/sec than at 0.2 rad/sec. These results support the observation made from Fig. A-7, that motion is much more important when handling qualities are degraded; it also suggests that the overall assessment of degraded configurations may be artificially worsened by motion cueing interactions.

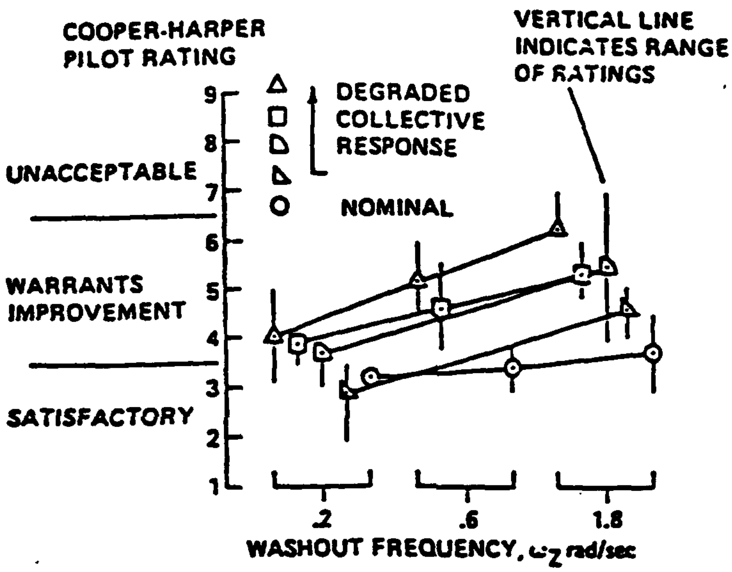


Figure A-8. Variation of Pilot Opinion Ratings of Vehicle Vertical-Response Handling Qualities with Vertical-Motion Fidelity (From Ref. A-7)

D. VISUAL/MOTION SYNCHRONIZATION STUDIES

The synchronization of visual scene with motion response is important for pilot comfort and performance. Improvements in computer-generated imagery (CGI) technology have reduced computational time delays for visual displays to levels well below the effective motion delays resulting from drive system lags. Furthermore, while the mass and inertia of the simulator make it impossible to fully compensate for the drive system lags, it is possible to provide very effective lead compensation in the visual imagery to eliminate virtually all computational delays in the frequency range of piloted control (Refs. A-20 and A-21). Thus it is possible, for frequencies as high as 10-20 rad/sec, to have essentially no response delay in the visual system while there are still relatively large delays in motion. Obviously the ideal situation is one in which both visual and motion responses occur simultaneously,

with no time delay. The important issue here, however, is whether it is better to synchronize the visual and motion responses — even if this might mean delaying the visual scene — or to compensate both to the fullest extent possible — even if this means a large visual/motion mismatch.

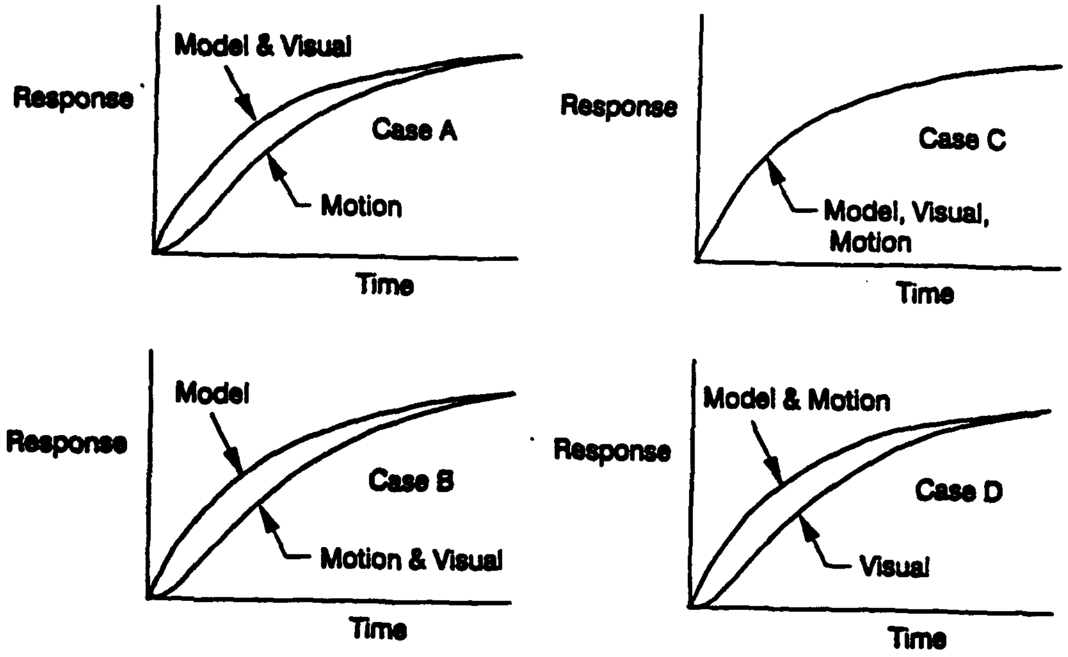
The issue of visual/motion synchronization has been addressed by several investigators. Unfortunately, as with many of the motion studies, the simulators used were not always capable of providing large-amplitude motion to begin with, so it is not always clear just what the benefits and penalties really are. Additional complicating factors also must be considered, e.g., fidelity of the motion; scene complexity and fidelity; task design and difficulty; dynamics of the simulated vehicle, etc. The following are a few of the more significant studies and their key findings.

Reference A-22 evaluated four visual/motion combinations on the NASA Ames Six-Degree-of-Freedom (S.01) simulator for a single-axis roll compensatory tracking task. No washouts or gain reductions were used in the simulator. The pilots tracked a sum-of-sines roll disturbance function displayed on a television monitor in the cockpit, and while performance measures such as pilot ratings and error scores were obtained, the only obvious differences between configurations were in the generation of pilot phase lead, as determined from describing-function data. The four configurations, and the pilot describing functions for two sets of aircraft roll dynamics, are shown in Fig. A-9. Overall results are as follows:

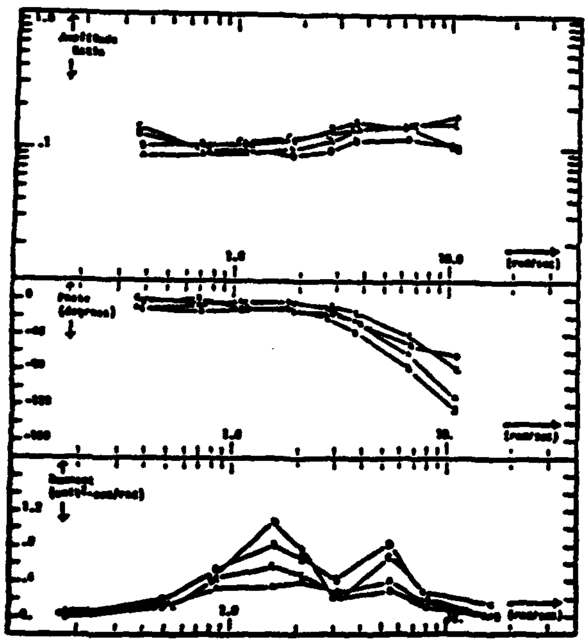
- <u>Case A:</u> Normal visual scene, normal motion (motion lagged visual by an effective first-order lag of $1/(.21s+1)$, producing a visual/motion mismatch). Baseline case.
- <u>Case C:</u> Normal visual scene, motion compensated to match. Best case overall in terms of performance; pilots generated lead at high frequencies when compared to the baseline case (Figs. A-12b and A-12c).
- <u>Case B:</u> Normal motion, visual lagged by $1/(.21s+1)$ to remove mismatch. Less high-frequency pilot lead, overall worst flown, similar to baseline.
- <u>Case D</u>: Motion compensated but visual lagged by $1/(.21s+1)$ to produce mismatch with visual lagging motion, opposite that of the baseline. Performance (errors) poor, but pilot describing functions very close to normal visual /compensated motion case.

The observations from the above are that 1) it is better to have motion lag visual (Case A) than to intentionally lag the visual just to reduce mismatch (Case B); and 2) in terms of pilot high-frequency lead generation, motion compensation is more important than visual compensation (Case D vs. Case A).

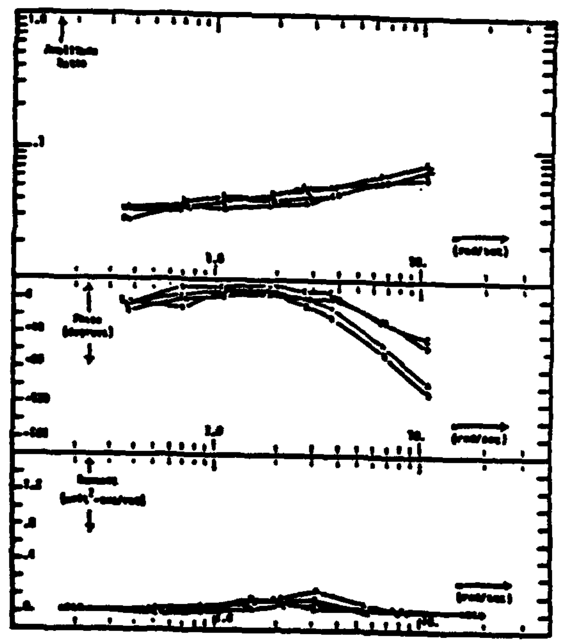
Reference A-23 also investigated visual/motion mismatch for a vertical pursuit tracking task (a target airplane flew a vertical path driven by a sum of sines signal), with a secondary task (tapping a metal kneepad with a stylus) added to assure full pilot workload. Three airplane configurations and



a) Time Responses; Mismatch is Represented by a Lag of $\frac{1}{0.21s + 1}$



b) Average Pilot Quasi-Linear Describing Function for Dynamics 1



c) Average Pilot Quasi-Linear Describing Function for Dynamics 2

Figure A-9. Visual/Motion Mismatch Study of Reference A-22
(Roll Tracking Study on NASA Ames S.01)

four motion sets were evaluated. The motion sets consisted of fixed-base, full motion, full motion with heave removed, and angular-only motion. The simulator used was the NASA Langley Visual/Motion Simulator; the limited travel of the simulator required use of a second-order washout in the heave axis, but no washouts were used in pitch, and the surge, sway, and yaw degrees-of-freedom were set to zero for all runs. Time delays were introduced in increments of 0.03125 sec, since this was the update rate of the digital computer used to drive both visual and motion. The estimated delay for the baseline visual camera-model system was 0.047 sec, and the estimated delay for the motion system pitch and roll responses was about 0.097 sec. The total delay for heave motion was approximately 0.14 sec. Visual and motion delays were introduced as "units," where one unit equals 0.03125 sec, with most of the runs performed for units of 0, 2, 4, 8, 12, and 16. Motion-system delay effects were evaluated only with an initial 8 units of time delay in the visual system, and therefore it is difficult to interpret these results. The more meaningful results were obtained for variations in visual time delay with no added motion delay.

In the Ref. A-23 simulation pilot performance, measured in terms of total tracking error and control activity, begins to deteriorate at around 4 to 8 units of added visual delay (total delay of 0.172 to 0.297 sec). This corresponds to a visual/motion mismatch of around 0.075 to 0.200 sec, compared with the pitch and roll motion responses. Interestingly, best performance was achieved in almost every case when two units of delay (0.0625 sec) were added to the visual system. This delay resulted in a total visual delay of 0.110 sec — very near the pitch/roll motion delay of 0.097 sec. In other words, in terms of errors, the best condition was when the mismatch between visual and motion was minimized. This result says that it is better to delay the visual response slightly to match motion, in direct conflict with the Ref. A-22 result above, although it must be noted that the improvement in performance in the Ref. A-23 experiment was quite small.

It was also found in the Ref. A-23 study that when visual/motion mismatch exceeded about 6 units (0.187 sec), the subjects tended to become nauseated.

Reference A-24 reports on a study of motion/visual mismatch conducted on a moving-base automobile driving simulator at Virginia Tech. Several physical and physiological measures of performance were obtained from subjects driving a simulated standard car; the simulator used computer-generated visual imagery with a four-degree-of-freedom motion base (roll, yaw, surge, and sway). Time delays of 0, 0.17, and 0.34 sec were added to either or both of the visual and motion systems. The conclusions from this experiment were similar to those of Ref. A-23: 1) that visual delay was more detrimental to performance and feelings of uneasiness than was motion delay; and 2) in the case of a visual/motion mismatch, it was better to have visual lead motion than vice versa.

Different results were found for the Air Force's Advanced Simulator for Undergraduate Pilot Training (ASUPT), Ref. A-25. This simulator employed a computer-generated visual scene with a synergistic six-leg motion base and a g-seat. The time delays in the motion system were excessive, measured by step inputs to be between 249 and 383 msec depending on the timing of the input. By contrast, the visual system responded with a total delay between 193 and 260 msec. It was found that compensation of the visual scene to account for only 67 msec of the visual delays, resulting in a total visual delay of 126-193 msec, "significantly improved the pilot's ability to perform the formation flying task in the simulator." The mismatch between visual and motion was even larger with the compensation, ranging from 123 to 190 msec. This significant improvement for a relatively small reduction in visual delays may more reflect the detrimental effect of such large time delays to begin with, rather than suggest that visual delays should be compensated to the maximum extent possible regardless of the motion delays. Further, what was not investigated was the possibly positive impact of reducing the motion delays so that they more nearly matched the visual delays. Based on the other studies cited above, it seems likely that this would have produced a similar, if not greater, result.

The general observations that may be drawn from the foregoing are that 1) it is better to have visual lead motion, rather than motion lead visual; 2) when motion time delay is small, it may be best to synchronize the visual and motion responses rather than attempt to remove all visual delays via compensation; 3) when the delays in both visual and motion are significant, even a small amount of compensation to the visual system may result in a large improvement in performance; and 4) excessive visual/motion mismatches (on the order of 187 msec or more) should be avoided to minimize potential for kinetosis.

E. SELECTION OF THE BASELINE AND MODIFIED WASHOUTS

The two sets of motion washout parameters evaluated in this simulation were devised to produce different forms of motion sensations for the pilot. The following describes the procedures followed in developing each of these sets of motion dynamics.

1. Baseline Set

The Baseline motion parameters were very similar to motion dynamics used in most low-speed helicopter simulations on the VMS. The philosophy at Ames in selecting motion gains and washouts has generally been to emphasize motion onsets (initial accelerations), since it is impossible to transmit sustained accelerations in the VMS environment. Thus the Baseline system was comprised of relatively high response gains with moderately large washout filters.

The initial set of gains and washouts was identical to that used in a previous simulation (Ref. A-26). To assure that this was a representative set of parameters, Mr. Richard Bray, who had recently retired from NASA, volunteered to assist in the adjustment of the Baseline dynamics. Portions of several simulation sessions were devoted to evaluations by various pilots of the Baseline set, with modifications by Mr. Bray as needed to provide a set of motion dynamics that fulfilled the objectives without unnecessary trips of the motion software limits. Once this process was completed, the Baseline gains and washouts were used for formal evaluations with no further changes.

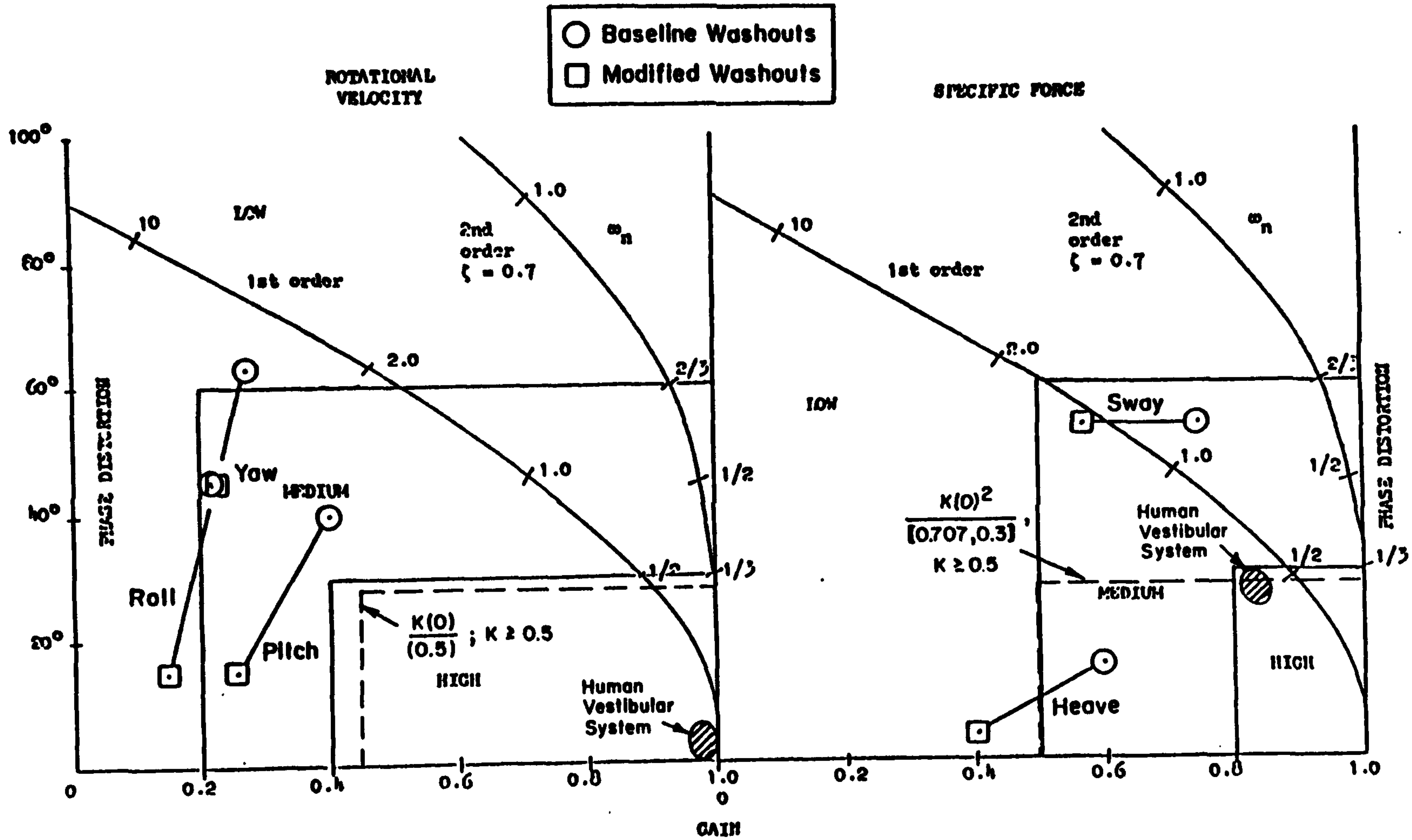
2. Modified Set

The Modified set of gains and washouts was devised iteratively, using a combination of piloted evaluations and tailoring of the frequency responses of the simulator to achieve the characteristics outlined below. The techniques used in identifying the cab motion frequency response are described in Appendix B. Several sessions were devoted to this endeavor, usually requiring an extensive period of non-piloted perturbations of the cab, generation of frequency response plots, and analysis of the plots to plan adjustments to the gains and washouts. Following this, a piloted evaluation of the new set of gains would be performed.

The goal of the Modified design was a set of motion parameters that minimized the phase distortion between the desired (aircraft model) and actual (cab) frequency responses. No formal criteria were adopted at the outset of this exercise; the two primary objectives were to attempt, as well as possible, to reduce the phase differential to 30 deg or less in the frequency range from 1 to 5 rad/sec, and to make a set of responses that were clearly different from the Baseline. Since this was intended to be an exploratory study, with a more complete evaluation planned for a follow-on simulation, it was decided that the emphasis would be on the cab responses in the directions of greatest displacement, i.e., heave, roll, and sway. Most of the development time was devoted to roll and heave; only a brief investigation was conducted for pitch (due to the limited displacements in pitch and surge on the VMS), and there was no attempt to modify the yaw response from the Baseline set. Sway dynamics were not investigated in any depth since the Baseline sway response is designed primarily to transmit proper tilt cues, and this was desired for the Modified response as well.

3. Comparison of Motion Washouts With Proposed Limits

Several possible limits on motion washouts were discussed earlier in this appendix. These limits include the following: 1) for first- or second-order filters, gain of 0.5 or greater with washout break frequency of no more than 0.3-0.5 rad/sec; 2) phase distortion of 30 deg or less over the frequency range from about 0.5 to 6 rad/sec; and 3) gain reduction and phase distortion within the high-motion-fidelity boundaries of Fig. A-5. As Fig. A-10 shows, the first and third of these limits are



HIGH: Motion sensations are close to those of visual flight
MEDIUM: Motion sensation differences are noticeable but not objectionable
LOW: Differences are noticeable and objectionable, loss of performance, disorientation

Figure A-10. Comparisons of Washout Parameters with Guidelines on Motion Fidelity at 1 rad/sec (see Fig A-5)

quite closely related: a first-order filter with a break frequency of 0.5 rad/sec and gain greater than 0.5 (plotted on the left part of Fig. A-10) corresponds almost exactly to the high-motion-fidelity boundary, while a second-order filter with damping of 0.707, frequency of 0.3 rad/sec and gain greater than 0.5 includes the high-fidelity limit, and a part of the medium-fidelity region, for specific force (plotted on the right part of Fig. A-10).

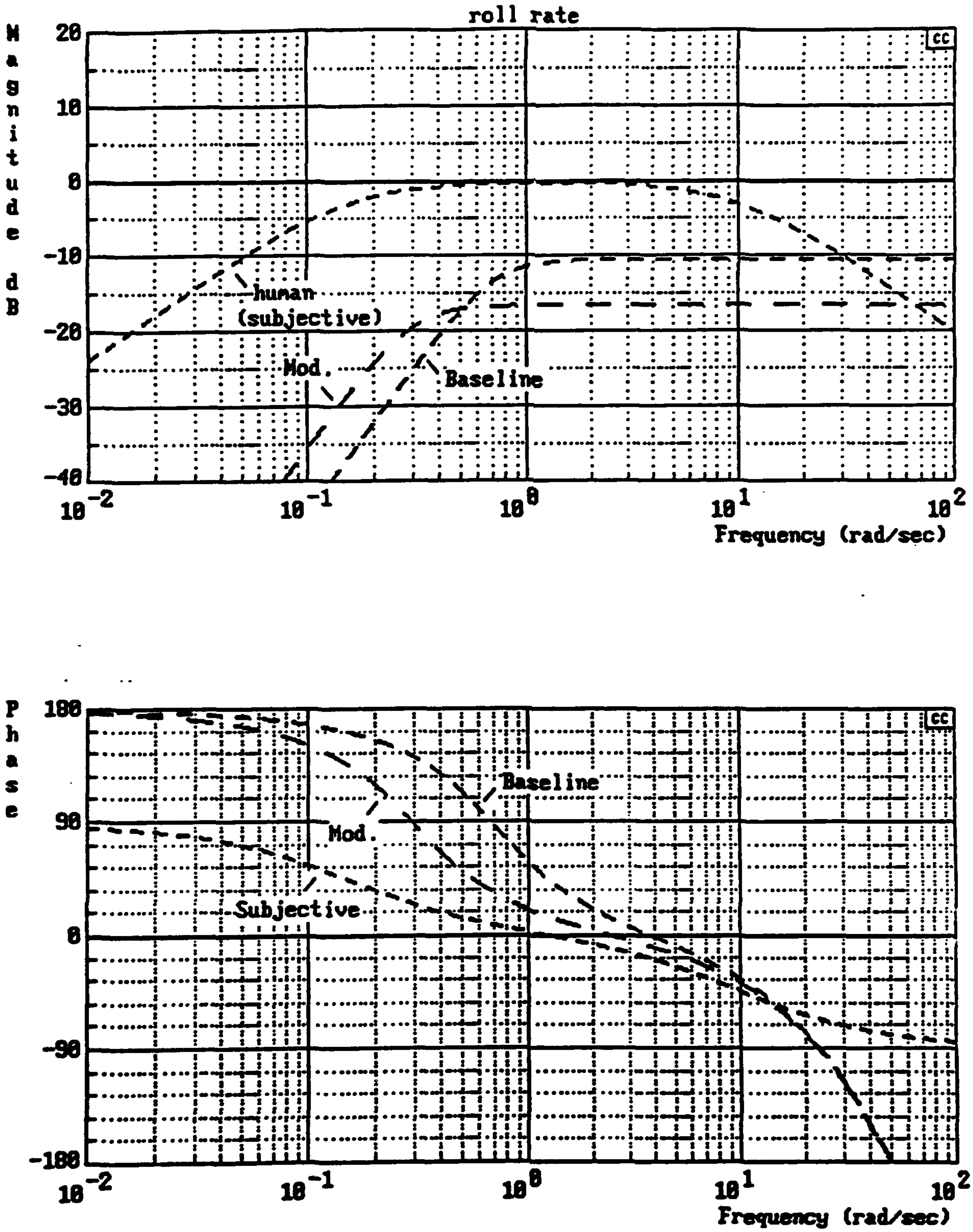
Figure A-10 shows the locations of the Baseline and Modified motion washout filters from the simulation. With the exception of yaw rate (where there was no attempt at modifying the response) and sway (where the only change was a reduction in gain), all of the modified washouts are characterized by a significant reduction in both phase distortion and gain. It is significant to note that in going from the Baseline washouts to the Modified set, there has been a direct tradeoff of gain for phase. This is a consequence of the motion displacement limits of the VMS — it is simply not possible to reduce phase distortion without giving up some high-frequency gain.

4. Comparison of Motion Washouts With Human Motion Sensing Models

The boundaries of Fig. 10 may, with some minor adjustments, be a valid method for assessing simulation motion fidelity. These boundaries effectively state how far the simulated motion may be from real-world motion without adversely affecting motion fidelity. Since we are ultimately interested in the pilot's perception of motion, however, it is also useful to consider the fidelity of motion by comparing simulated motion with the subjective sensations of motion. Given the impossibility of replicating real-world motion, it seems reasonable to allow for differences at those frequencies where the pilot is least likely to be aware of them. For this, we use the models for the human vestibular system discussed earlier (Figs. A-1 and A-2).

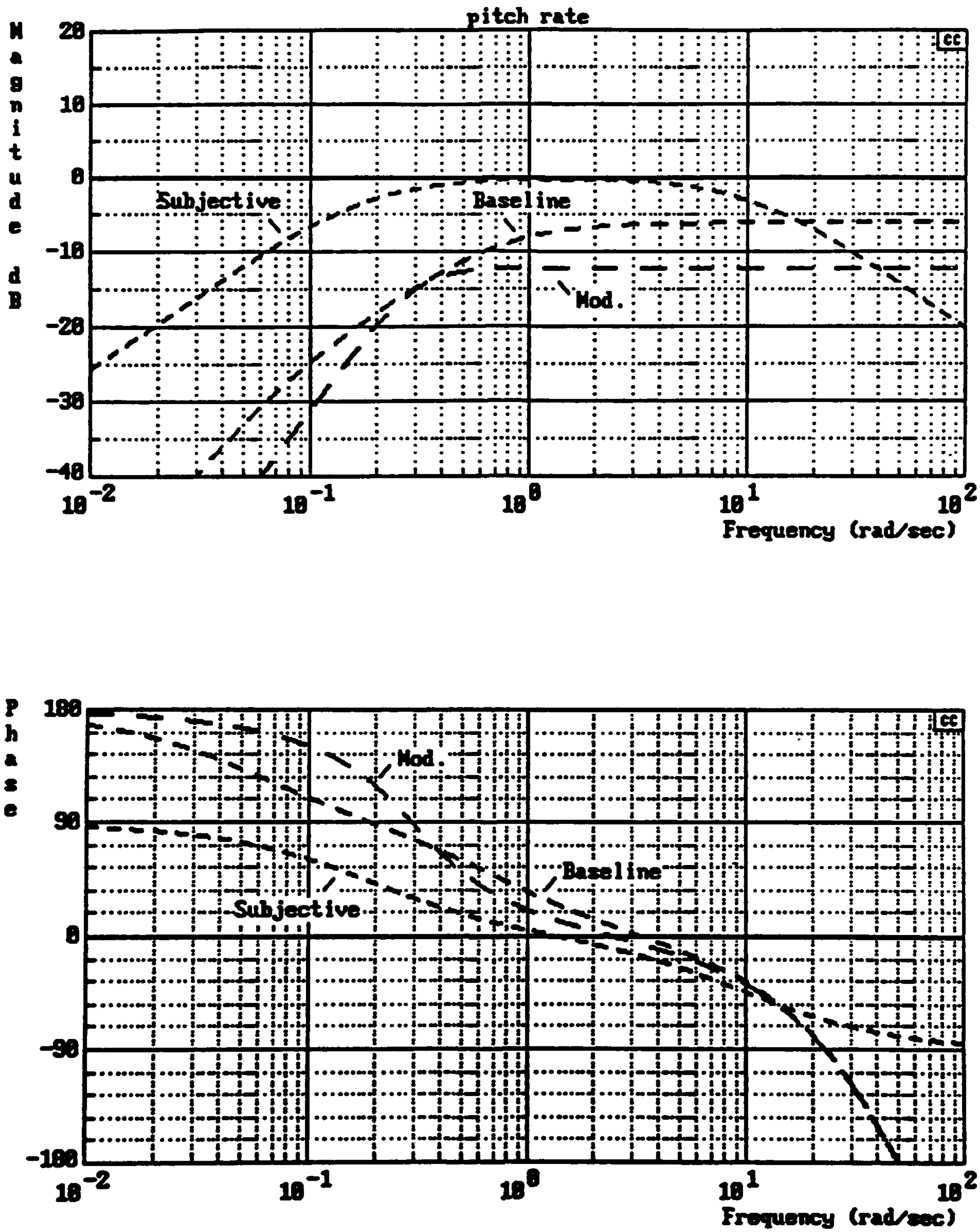
Figure A-11 shows frequency responses of roll rate, pitch rate, and vertical acceleration for the vestibular system and for the Baseline and Modified motion washouts. Since we know that there are inherent lags in the VMS motion drives (see Appendix B), and that these lags can be approximated reasonably well by pure time delays, the washout model responses in Fig. A-11 include the effective time delays for the VMS (70 msec in roll and pitch and 160 msec in heave). (Approximations are used in Fig. A-11 for convenience; the measures of the motion responses described below were extracted from measured frequency responses in Appendix B for all but sway.)

The roll rate responses (Fig. A-11a) exemplify the magnitude and phase differences introduced in the VMS by the combination of washouts and delays. As described earlier, the response of the semicircular canals to a roll rate is effectively a first-order washout at low frequencies and a lag at high frequencies. On the VMS the motion washout is a second-order filter; the break frequency for the Baseline system (0.7 rad/sec) is well above the vestibular washout, resulting in



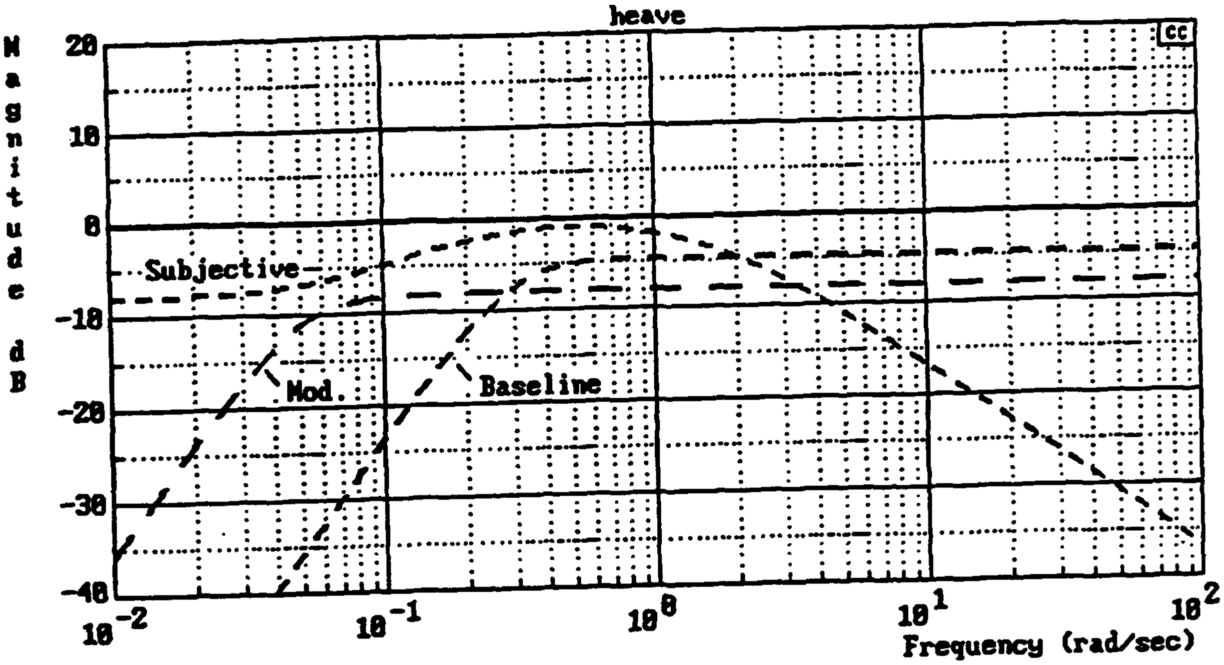
a) Roll Rate

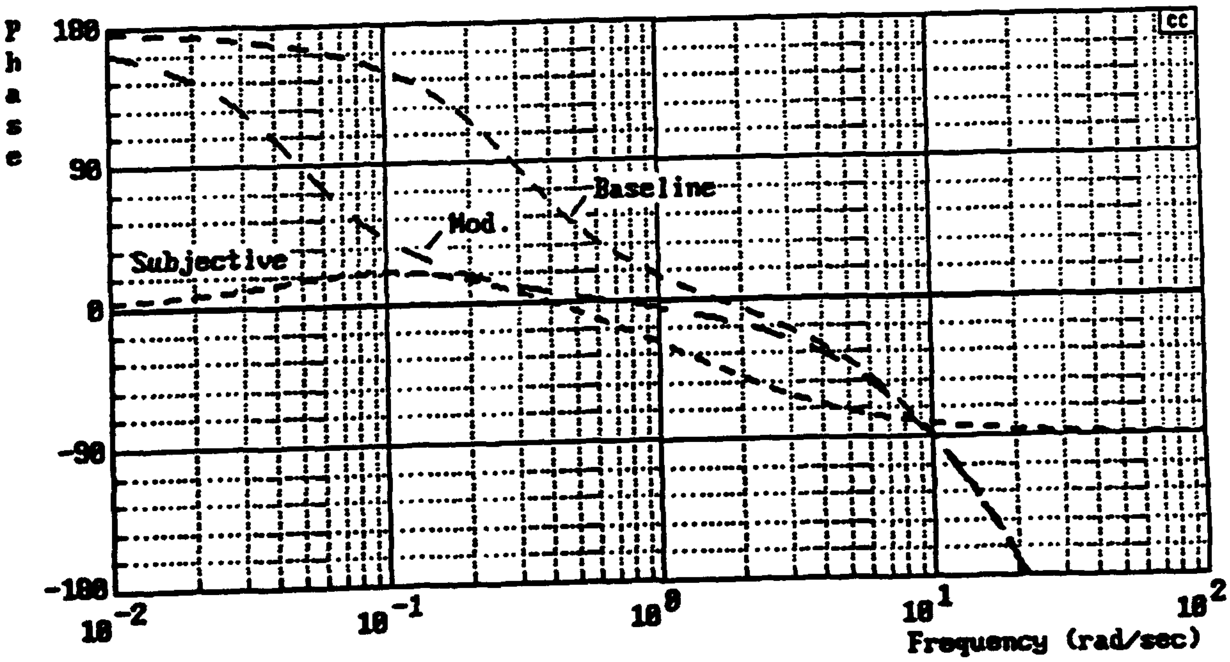
Figure A-11. Comparison of Frequency Responses of Human Vestibular System and Motion Washout Filters (Washout Filters Include VMS Response Delays)



b) Pitch Rate

Figure A-11. (Continued)





c) Vertical Acceleration

Figure A-11. (Concluded)

substantial reductions in amplitude at low to mid frequencies (approximately 0.2 to 1 rad/sec) and a significant phase difference up to about 2 rad/sec. By contrast, the Modified washout, with a lower break frequency of 0.3 rad/sec, attenuates amplitude at all frequencies but with much less phase distortion, resulting in reasonable correspondence with the subjective response at frequencies above about 0.6 rad/sec. Pitch rate, Fig. A-11b, is very similar to roll rate.

There is an even greater phase difference between the pilot's sensation of vertical acceleration and the response of the Baseline motion washout, Fig. A-11c. In this case the gain reduction is not great, but the phasing is incorrect at almost all frequencies: the simulator correctly represents real-world phase at only a single frequency (2 rad/sec), and lags even the pilot's perception of motion above 10 rad/sec. The Modified washout is a considerable improvement in phase, compared to either real-world phase (i.e., zero degrees) or to the pilot's perceptions, at the expense of magnitude of response. In addition, the phase angle for the Modified motion washout is closest to both the real world and the pilot's subjective response for the frequency range of 0.1 to 1 rad/sec — the region where closed-loop altitude control is most likely.

The frequency responses of Fig. A-11 suggest that an alternative to the "snapshot" approach of Fig. A-10 is needed for specifying motion requirements. This alternative would be based on the 30-deg phase-distortion limit mentioned earlier, e.g., above what frequency (or over what range of frequencies) is the simulated response within ±30 deg of some reference response? For the reference, we could use the vestibular system models, as in Fig. A-11, but since there are other slightly differing forms of these models, it makes more sense to simply compare the simulated motion as a phase distortion, as is done for Fig. A-10. Clearly, phase distortion is not the only answer; we still need some measure of gain attenuation. For this, the choice of 1 rad/sec for angular velocity, as is used in Fig. A-10, is reasonable since it is in the middle of the range of frequencies of highest pilot perception of motion (e.g., Fig. A-11a) with lowest phase distortion. For linear acceleration (or applied specific force), however, the subjective response in Fig. A-11c suggests a somewhat lower reference frequency, near 0.5 rad/sec. Therefore, a possible alternative to Fig. A-10 is a crossplot of gain at a reference frequency (either 0.5 or 1 rad/sec) vs. minimum phase distortion frequency (above which phase distortion is less than 30 deg).

Figure A-12 shows such a crossplot for angular velocity (Fig. A-12a) and specific force (Fig. A-12b). Besides addressing the pilot-centered concerns of phase distortion, this approach has another distinct advantage over that of Fig. A-10: it is possible to further specify upper limits on distortion as well, e.g., phase rolloff due to motion lags and time delays. No upper limits are shown in Fig. A-12; the development of such limits will require further experimentation.

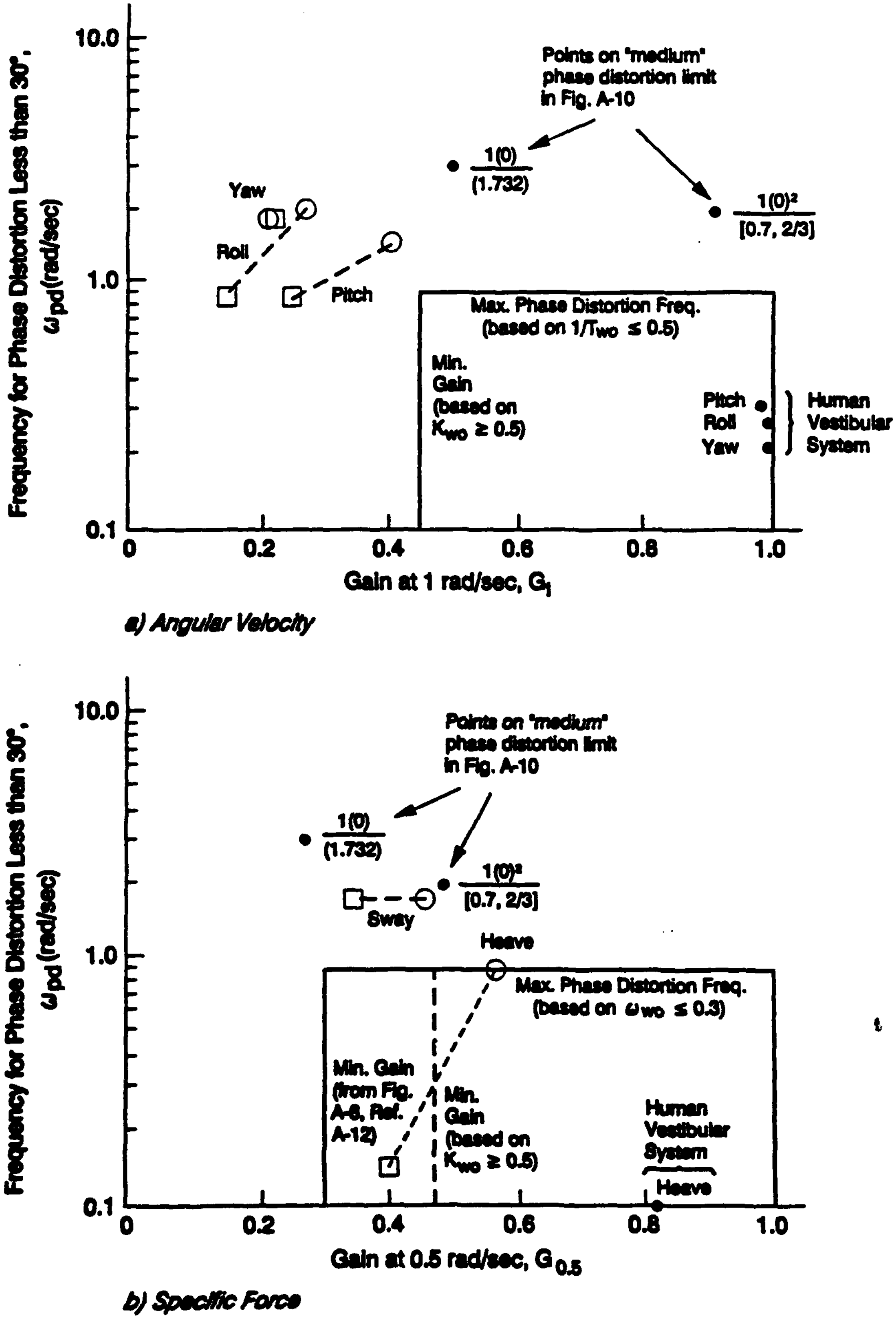


Figure A-12. Proposed Limits on Motion Fidelity Based on Phase Distortion and Gain

There are other differences between the phase-distortion-frequency plots of Fig. A-12 and the frequency-specific plots of Fig. A-11. For example, the Medium-fidelity line in Fig. A-11 allows 60 deg of phase error at 1 rad/sec, corresponding to both a second-order washout at 2/3 rad/sec and a first-order washout at 1.73 rad/sec. The latter number, especially, seems quite high since this places the breakpoint in the middle of the expected piloted crossover frequency. On the basis of frequency for 30 deg of phase distortion, Fig. A-12, this first-order washout exhibits excessive distortion up to 3 rad/sec, or above the expected crossover frequency. The first- and second-order washouts plot differently on Fig. A-12, with phase-distortion frequencies of 3.0 and 1.9 rad/sec, respectively. Hence the second-order filter may in fact be moderately acceptable, but the first-order seems unreasonable, even though these washouts have the same amount of phase distortion at 1 rad/sec (Fig. A-11).

The limits for high motion fidelity in Fig. A-12 (solid boxes) are based on the washout recommendations in this appendix. In addition, the results of the roll-sway coordination study of Ref. A-12 (i.e., Fig. A-6) suggest that a relaxation in gain from 0.5 to 0.3 may be acceptable. Since the Baseline and Modified washouts all lie outside the high-fidelity region (with the exception of heave), it is not possible to determine from the current simulation whether these limits are reasonable.

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APPENDIX B

VERIFICATION OF SIMULATION FROM FREQUENCY RESPONSES

APPENDIX B

VERIFICATION OF SIMULATION FROM FREQUENCY RESPONSES

A. INTRODUCTION

Three forms of frequency-response identification were employed during the simulation to verify the models and to determine the time delays in the Vertical Motion Simulator. This appendix describes the three methods, including their advantages and disadvantages, and shows example results from each. The data are then applied to determine the overall time delays in the simulation, including visual and motion system delays.

It is important to point out that it is not the intent of this appendix to present a thorough analysis of frequency-response identification techniques, nor is it to critique the dynamic characteristics of the VMS facility. Instead, the purpose here will be only to document the methods used to verify the major elements of the simulation to the extent required to gain confidence in the handling qualities data presented in the main body of this report.

Most of the information presented herein, including especially the timing data and RSVP program output, is due to the contributions of Mr. R. E. McFarland of NASA Ames Research Center.

B. SOURCES OF TIME DELAY IN THE SIMULATOR

The time delays incurred in simulations on the VMS have been measured in the past by various techniques, and most of these measurements have been subject to question for one reason or another. Because of the emphasis on time delay itself in the test plan for this simulation, it was critical that an accurate assessment of time delays be made before the simulation began. To this end, prior to the start of the simulation a series of timing charts was generated, along with the plans for an online frequency-analysis program to measure the delays (Refs. B-1, B-2, and B-3). Figure B-1 is a synchronization diagram for the simulation, showing the locations and types of known time delays throughout the VMS facility. This chart was used to determine compensation required with one of the frequency-analysis methods and was used as a reference for all subsequent analysis. It is described in detail below.

1. Known Delays

Most of the sources of time delay in the VMS are known delays — that is, they are purely functions of computer cycle time and hence can be predicted analytically (and verified with the frequency-response software described below). Several elements, however, produce unknown amounts

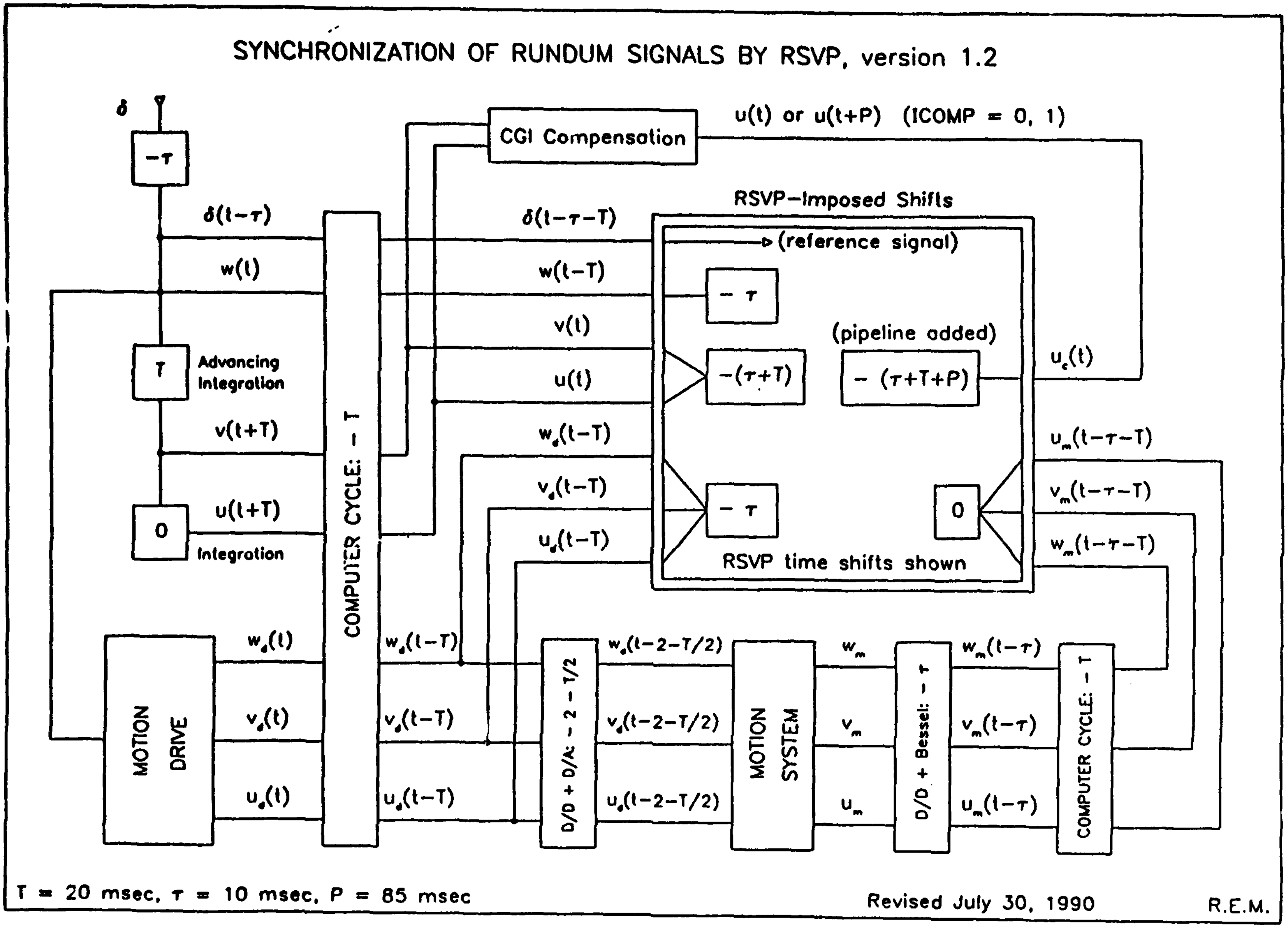


Figure B-1. Sources of Known Time Delays in the VMS Facility, and Synchronization of Measured Signals for RSVP (From Ref. B-3)

of delay — specifically the cockpit feel systems and the motion system itself — and these must be measured.

The most obvious of the known delays (Fig. B-1) is computer cycle time, T, which was 20 msec for this simulation. As Fig. B-1 shows, acceleration signals computed by the math model software, w(t), are subject to a 20-msec delay, but rates and positions, v(t) and u(t), are not: an advancing-integration algorithm is employed in the software to provide a one-cycle effective time lead on rate and position computations.

Additional known delays include the time required to create the CGI visual image; based on Ref. B-4, the total time for computing one cycle of visual image is τ_{CGI} = 33.3 msec (30 cycles/sec), and it takes 2.5*τ_{CGI} to generate the image necessary to fill one-half of the lines on the screens in the cockpit, or 83.3 msec. A lead compensation algorithm (Ref. B-4) is used to effectively remove this time delay in the frequency range for piloted control (e.g., below approximately 20 rad/sec).

Other small sources of delay include analog-to-digital (A/D) and digital-to-analog (D/A) interfaces, as well as D/D connections. Generally, these delays are on the order of 2-10 msec and hence are within measurement error by most measurement methods.

2. Unknown Delays

The most significant sources of unknown delay, as mentioned above, are the cockpit force feel systems and the VMS motion system. No detailed measurements of the feel system were made; approximations to the pitch and roll feel-system dynamics were made based on pot settings for the control loaders, as documented in Section II of this report. Motion system time delays are critically important, and as a result a considerable amount of attention has been devoted to determining the effective time-delay properties of the VMS. The results of this study are included in this appendix.

C. ONLINE FREQUENCY ANALYSIS (RSVP)

All analysis and verification of the models that was conducted during the course of the simulation was performed with software developed as a part of the simulation. This software, RSVP, for RUNDUM Spectral Visualization Program (Refs. B-2 and B-3), generates and applies to the simulation a sequence of Gaussian noise inputs scaled over a range of frequencies. After a run in any one axis of approximately two minutes, the resulting digital time-history data was transferred to another computer for analysis by the RSVP software and final graphical output from an Apple Macintosh computer. This transfer required approximately five to ten minutes, at which point the simulation could continue while plots were generated from the RSVP results.

1. Corrections for Time Delay

Output from RSVP consisted of transfer function data, which were then presented graphically in the form of Bode plots over a frequency range of 0.1 to 20 rad/sec. RSVP was configured to correct the responses for time synchronization differences as required (Fig. B-1) to properly represent the VMS simulation setup and place all of the responses on a comparable time sequence, referenced to the measured cockpit control deflection signal. For example, as Fig. B-1 indicates, the measured motion response signals incurred exactly the same time delays as the measured reference control signals, i.e., $\tau + T$ sec, and therefore required no time shifts. By contrast, the model rate and position signals, v(t) and u(t), required addition of a time delay equivalent to one cycle of the main computer, T, to remove the effect of the one-cycle advancing integration algorithm mentioned above, plus a delay equivalent to the measurement delays for the cockpit control signal, τ. It is important to note that Fig. B-1 does not relate all signals back to the cockpit signal; rather, they are referenced back to the sampled control inputs. Since RSVP generated frequency-response plots based on control inputs, it is important only to preserve the correct relative timing.

It was not possible to physically measure the cockpit visual image generation response; instead, the command from the main computer to the CGI computer was recorded and a total time delay of 113 msec added. This represented the one-cycle delay, T, (20 msec) for advancing integration and the measurement delay, τ, (10 msec), plus 83 msec for the image generation (pipeline) delay, P (Fig. B-1).

The RSVP-imposed time shifts for the various signals are indicated within the double box in Fig. B-1. Subscripts on the measured signals indicate their source and location throughout the VMS facility. For example, non-subscripted variables, e.g., $\delta(t)$, w(t), v(t), and u(t), are all model-referenced signals; a d subscript ($w_d(t)$, etc.) reflects motion drive command signals; an m subscript ($w_m(t)$, etc.) indicates output of the motion system itself; and a c subscript ($u_c(t)$) indicates output from the CGI computer.

2. Limitations of RSVP as Implemented

As implemented for this simulation, the RSVP software had several limitations that precluded its use for documenting all axes of response for all configurations evaluated. The version of RSVP applied in the simulation was a new, developmental program, and time limitations prevented implementation of all features required of a comprehensive on-line analysis package. Following this simulation, work has commenced on more complete analysis and verification software to replace RSVP as a standard tool for all future simulations on the VMS.

The most serious limitation to RSVP for this simulation was the requirement to have pitch and roll attitude stabilization for the helicopter model. Since RSVP applied a sequence of random noise disturbances to the math model, pitch and roll Rate Response-Types could not be analyzed, since the open-loop inputs forced the aircraft away from trim attitude with no restoring command. All analysis with RSVP was thus restricted to the pitch and roll Attitude Response-Type only. This was not true for the vertical-axis and yaw-axis responses, where the deviations from trim position and rate were linear and therefore did not cause the model to crash.

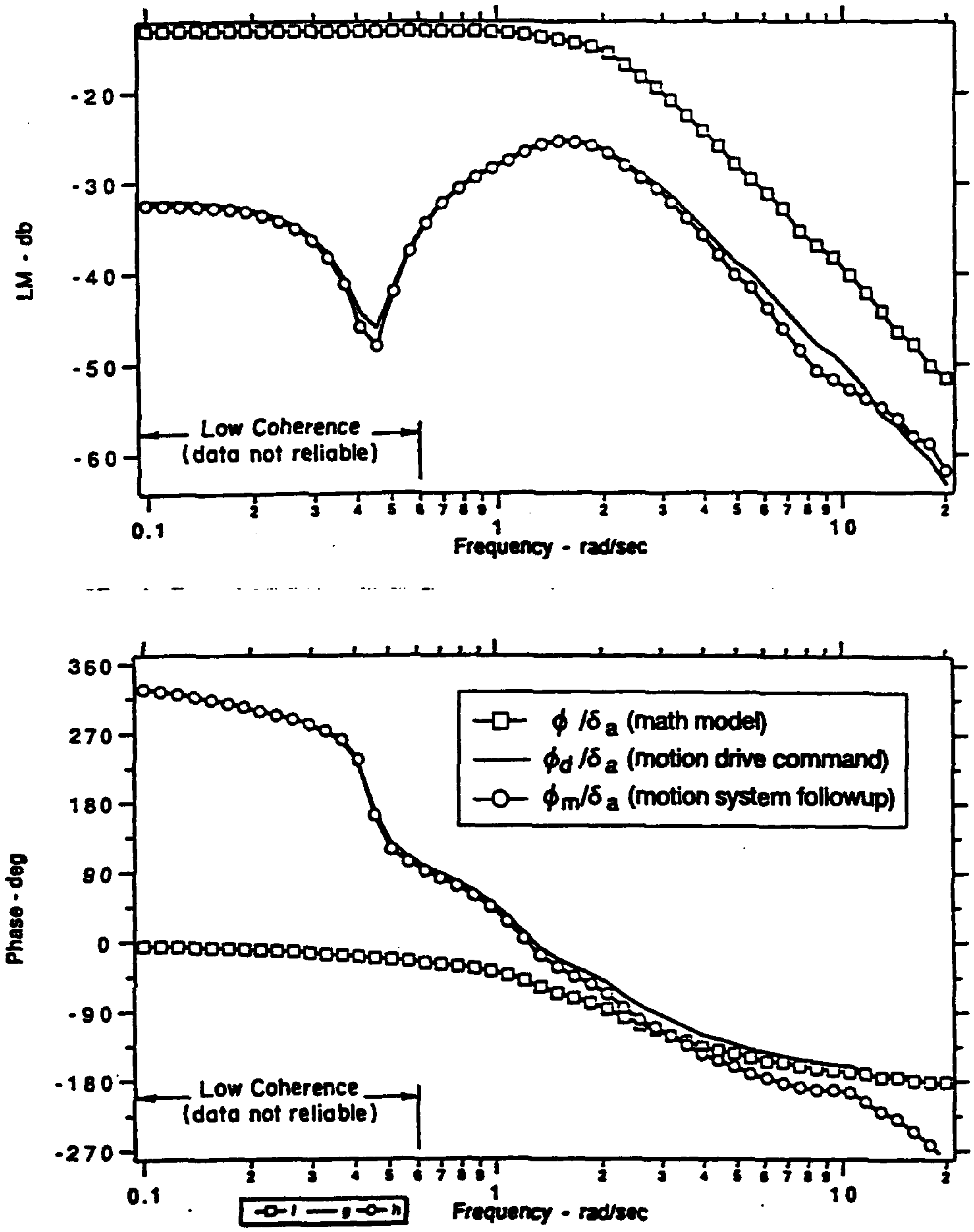
There were two other limitations that existed at the time of the simulation, but that would have correctable given development time that was not available: 1) RSVP produced valid output only down to about 0.5-1 rad/sec, below which the results are not reliable. This was generally low enough to verify model responses in the region of piloted control, but not for other uses, for example to verify break frequencies of the motion washout filters. 2) There was no measure of the goodness of the data, e.g., frequency responses of input and output power or coherency between output and input were not generated. Thus, confidence in the data is highly judgmental, based primarily on a combination of one's expectations and the general smoothness of the frequency responses. Later verification of the power and coherence of the RSVP data was performed using the CIFER software at Ames Research Center (e.g., Ref. B-5).

Despite these shortcomings, RSVP was extremely valuable as an online design and analysis tool, providing the ability to rapidly evaluate changes in aircraft control system parameters and motion washouts and response gains. The Modified motion system (Appendix A) was developed through repeated operation of RSVP (in combination with piloted assessments).

3. Example Output from RSVP

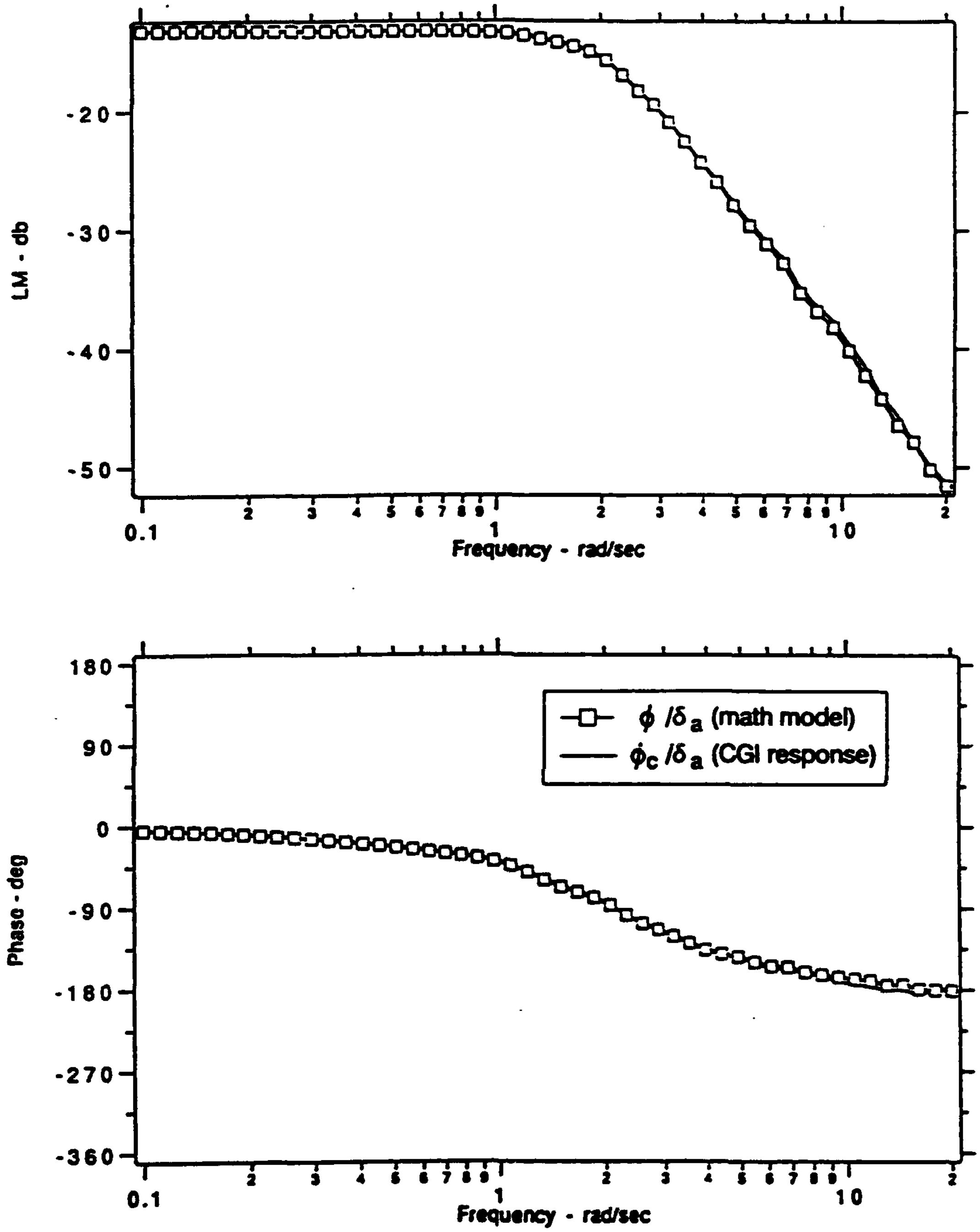
RSVP frequency responses were generated for all axes of control for the Baseline and Modified motion washout sets, as well as for added-delay and visual-compensation-off cases. Rather than present the entire set of responses here, an example set will be shown to illustrate the output from RSVP. It is important to bear in mind that most data below 0.5-1 rad/sec in these data plots have low coherence and thus should not be trusted.

Figure B-2 shows the responses of bank angle to roll commands from several points in the simulation. Figure B-2a compares the math model (ideal) response, ϕ/δ_a, with the VMS motion drive command signal, ϕ_d/δ_a, and response, ϕ_m/δ_a. The math model response (square symbols) is for the ACAH Response-Type (corrected by 30 msec for advancing integration and measurement delays, $\tau + T$, as indicated by Fig. B-1). From Fig. B-2a, it is possible to verify that this system has a Bandwidth of 4.0 rad/sec, as designed. The significant low-frequency phase lead between the math



a) Responses of Math Model, Motion Drive Command, and VMS Cab Motion Followup

Figure B-2. Example Responses from RSVP (Bank Angle Response to Roll Commands, Baseline Motion)



b) Responses of Math and CGI (resolved to cockpit visual image)

Figure B-2. (Concluded)

model and both the VMS motion command (solid line with no added symbols) and motion followup (circle symbols) represents the large washouts for the Baseline set. (Again, the low-frequency data should not be trusted too heavily; for example, the apparent "dip" in the magnitude curve at about 0.4 rad/sec is an artifact of the measurement and did not actually exist in the motion system.) At high frequencies, the phase angle of the motion command follows the math model, but the cab cannot keep up. This phase difference is the effective time delay of the VMS motion system, and is discussed in more detail later in this appendix. The difference in magnitudes between the math model and the motion command and response is due to the motion gain.

Figure B-2b shows a comparison of the math model response and the CGI visual image response, the latter corrected to represent the cockpit image by adding the pipeline delay P = 83 msec (Fig. B-1). The visual image response overlays the math model almost perfectly.

4. Development and Verification of Modified Motion Washouts

As mentioned previously, RSVP was most valuable in developing the Modified set of motion gains and washouts evaluated in the simulation. Washout frequencies were generally set based upon a goal of improving the phase curve matches of the math model and VMS motion responses over a frequency range of approximately 1-5 rad/sec (Appendix A). For the Baseline motion washouts, typical of past rotorcraft simulations at NASA Ames, the phase curves of model and motion match over only a small range (compare ϕ and ϕ_m frequency responses in Fig. B-2a) due to the large washouts employed.

With the lower washout frequencies used in the Modified filters the mismatch at lower frequencies is reduced (Fig. B-3). Iterative application of RSVP, with alternating piloted evaluations, was used to set the Modified set of motion washouts. At the same time, the reduction in washout frequencies mandated a corresponding reduction in motion gains, as evidenced by comparing the difference in magnitudes between math model and motion at high frequencies for the Baseline (Fig. B-2a) and Modified (Fig. B-3) motion washouts. The high-frequency phase rolloff is unaffected, of course, since it is a result of the mass and inertial properties of the motion system.

5. Verification of Added Time Delays

RSVP was used to verify that the time-delay circuitry properly injected time delays into the overall simulation (see Section II). Figure B-4 is one example plot, for which 200 msec of time delay has been added to the system. (This response is for the Modified motion filters and hence should be compared with Fig. B-3). While there has been no change in the magnitude characteristics in

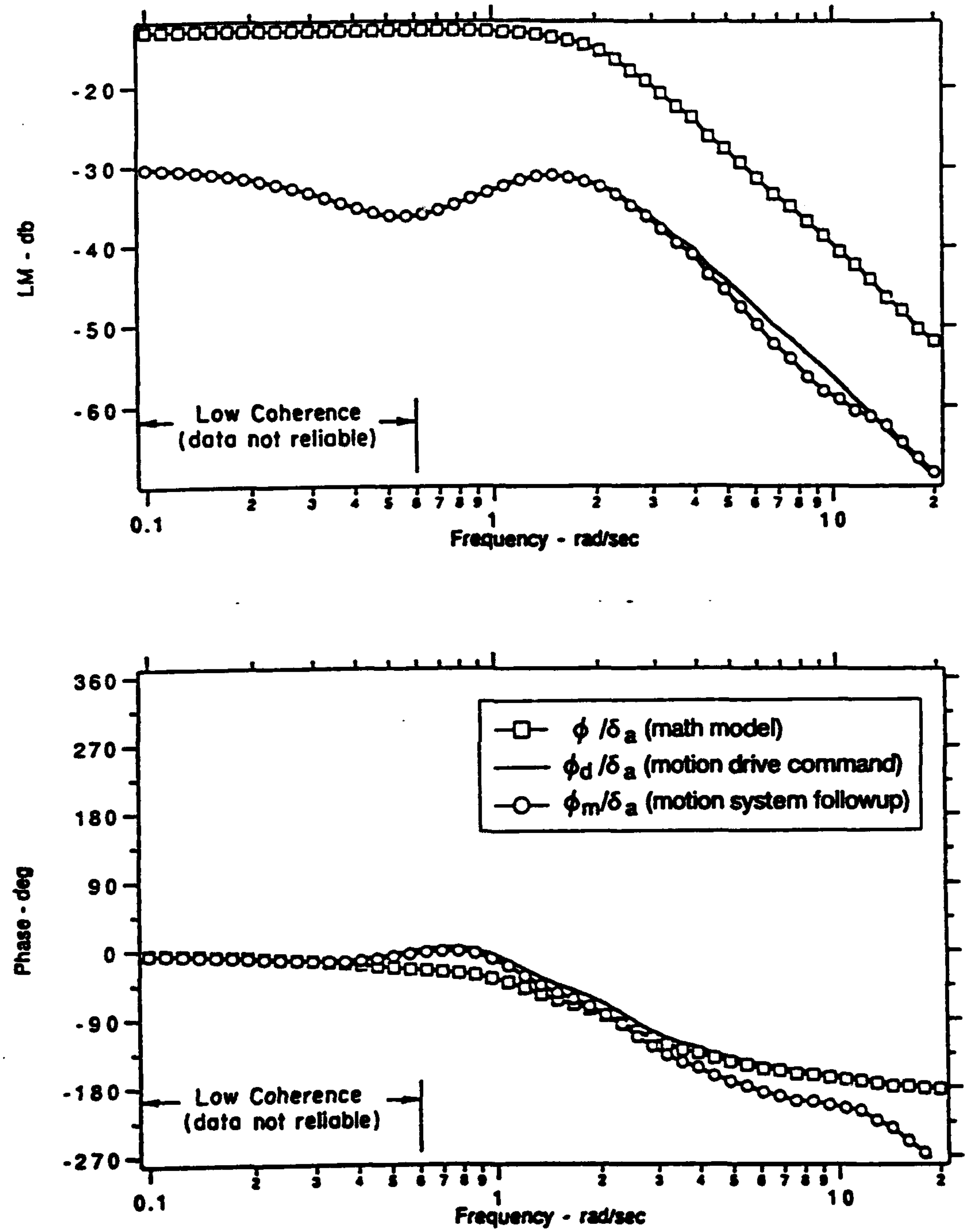


Figure B-3. Responses of Bank Angle to Roll Commands for Modified Motion System (Compare Fig. B-2a)

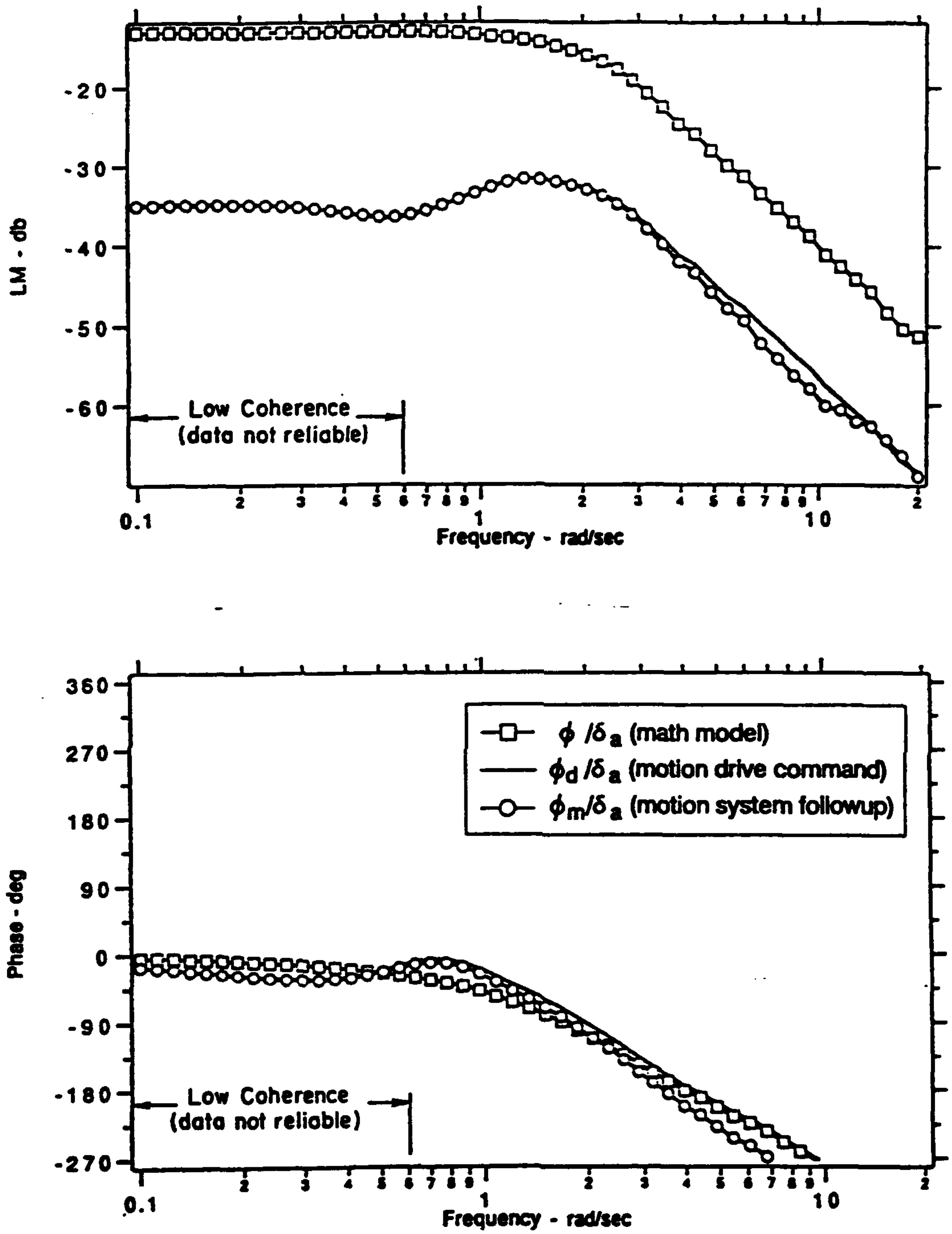


Figure B-4. Effect of Added 200 msec Time Delay on Bank Angle Responses (Modified Motion; Compare Fig. B-3)

Fig. B-4, the phase curves all show a consistent rolloff at high frequencies that corresponds to 200 msec of added time delay.

6. Verification of Visual Compensation Algorithm

RSVP responses were generated for the CGI visual image response with the visual compensation filter both on (as for Fig. B-2b) and off. Figure B-5 is one example of the response with the filter removed; the difference in phase between the math model and resolved CGI responses is 83 msec, as expected.

D. POST-SIMULATION FREQUENCY ANALYSIS

Frequency-response analysis of the simulation elements was continued after the simulation using Comprehensive Identification from FrEquency Responses (CIFER) software. This software, developed under the auspices of the Army at Ames Research Center (Ref. B-5), uses chirp-z transform (advanced fast-Fourier transform) techniques to determine frequency responses from time response data. CIFER generates output/input frequency responses, as well as numerous cross- and auto-correlation data, plots of input and output power, and coherency.

The post-simulation analysis served four purposes: 1) It provided an independent verification of the RSVP results. For this, the identical time-history data used by RSVP was analyzed with CIFER and similar plots were generated. 2) It allowed documentation using entirely different data forms. For this, pilot-generated frequency sweeps were generated and analyzed with CIFER for comparison with the Gaussian-noise-generated RSVP data. 3) It allowed for verification of the dynamics of the Rate Response-Types. Since only ACAH could be used with RSVP without causing the simulation to crash, analysis of the angular Rate Response-Types was impossible. Pilot-generated sweeps, however, could be easily performed for these systems, since the pilots could inject small closed-loop corrections on top of their sweeps to minimize attitude deviations from trim. 4) It provided measurement of the goodness of the RSVP data by generating power and coherence plots corresponding to the RSVP plots. For example, Fig. B-6 is typical of the coherence for angular rate and acceleration responses for Gaussian-noise-derived signals analyzed by CIFER. As this plot shows, coherence is low (below about 0.8) for frequencies below about 0.6 rad/sec. The "dip" in coherence in Fig. B-6 corresponds closely to the dip in the magnitude plot for the motion response in Fig. B-2a.

An example frequency response from CIFER for a pilot-generated frequency sweep is shown in Fig. B-7. This response was generated by concatenating three separate sweeps of approximately 70-90 sec each. A 60-sec window has been applied; further detailed smoothing and windowing is possible (e.g., Ref. B-5), but was not performed here, since the primary intent was to verify the RSVP results

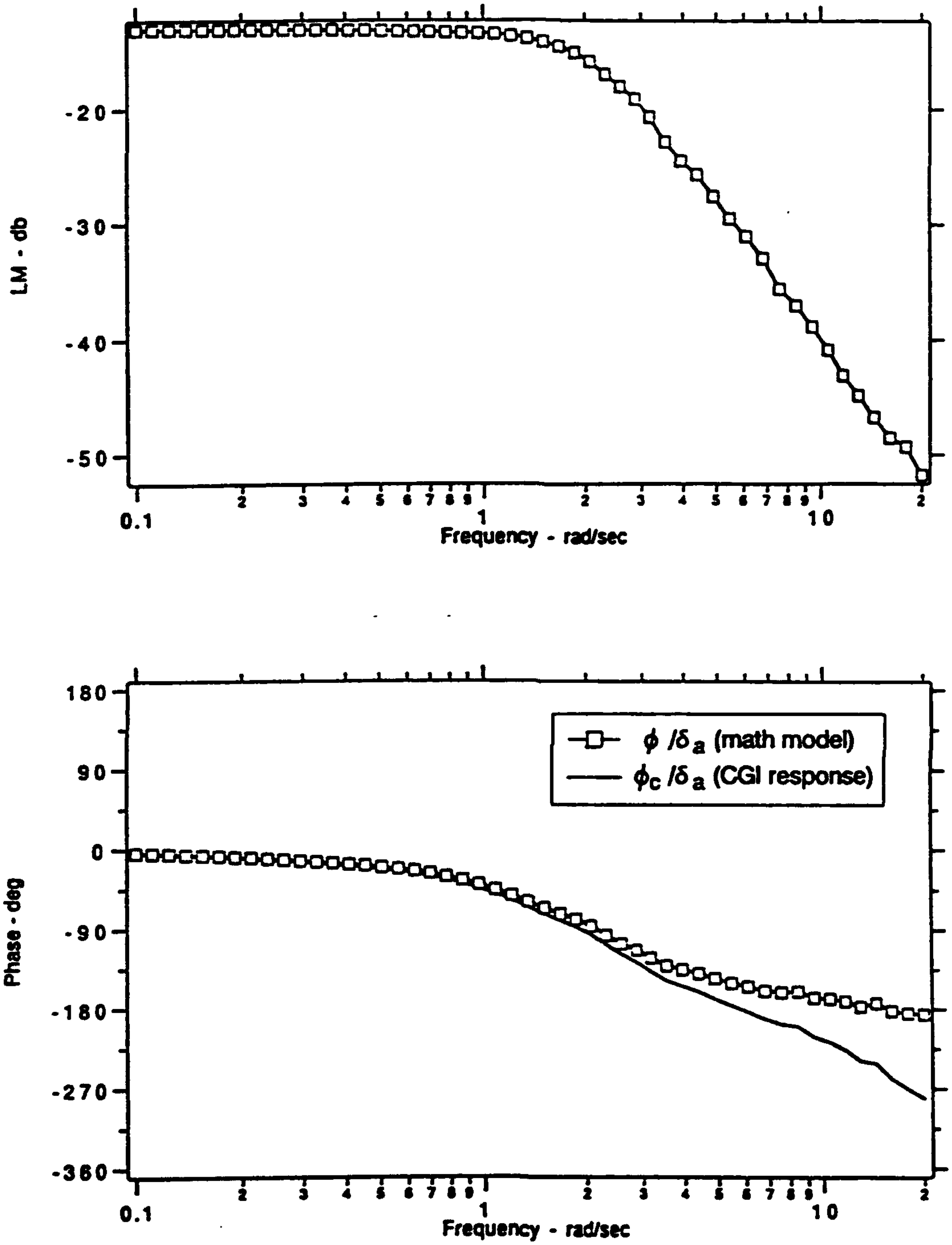


Figure B-5. Effect on CGI Response of Removing Visual Compensation Filter (Compare Fig. B-2b)

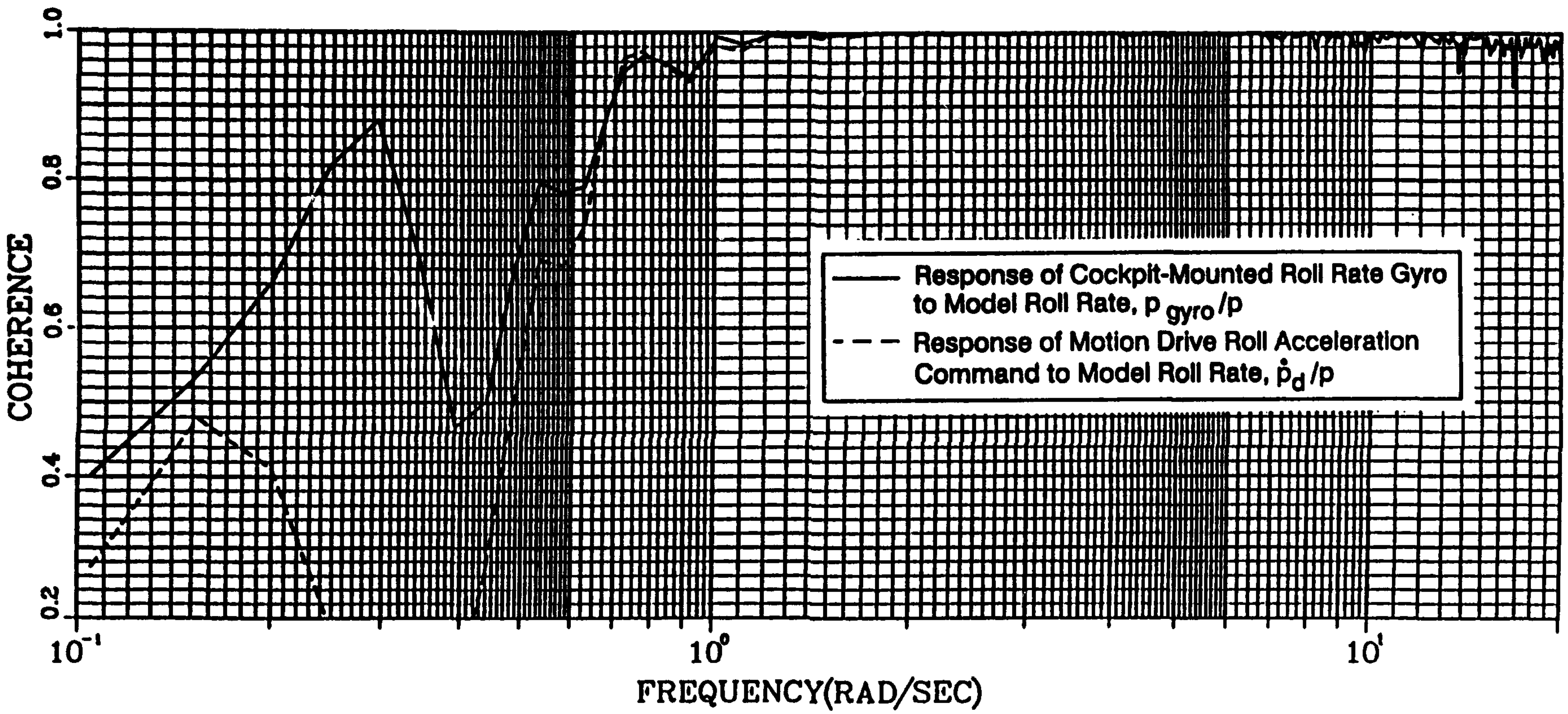


Figure B-6. Typical Coherence Plot for RSVP-Generated Time History Data Analyzed Using CIFER

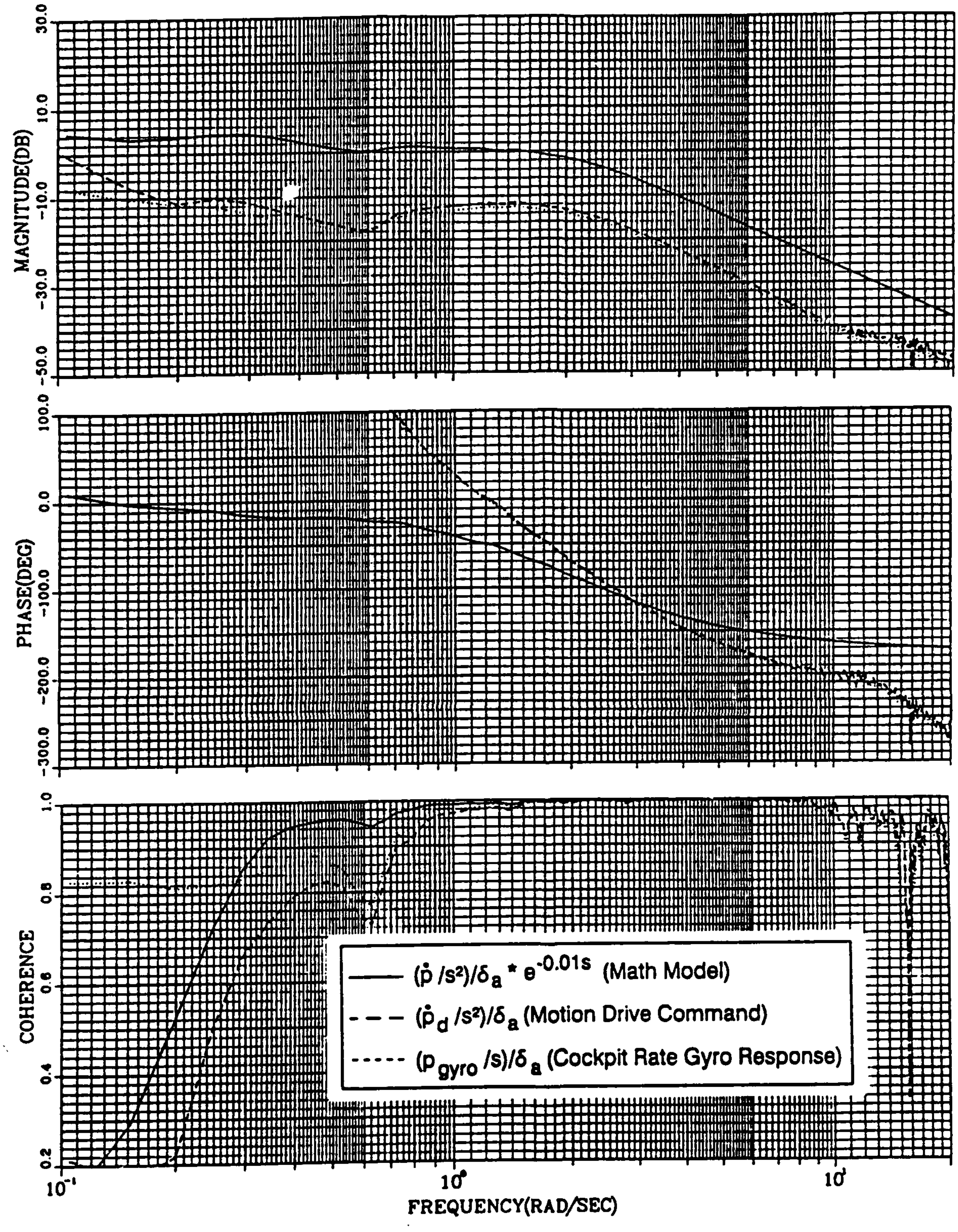


Figure B-7. Example Output From Pilot-Generated Roll Frequency Sweep of Rate Response-Type. All Signals have been Adjusted by s^{-n} to Resolve Responses to Effective Bank Angle for Comparison with Fig. B-2a

and not to conduct an indepth parameter identification analysis. The time-history responses used to generate the frequency responses of Fig. B-7 were from roll rate and acceleration measures, but have been resolved (by dividing by the proper power of s) to equivalent bank angle responses for direct comparison with Fig. B-2a. Comparison of Figs. B-2a and B-7 confirms the accuracy of the RSVP results, for frequencies above 0.6 rad/sec. (The gain difference between the two plots is due to using different pickoff points for the input signals.)

E. EVALUATION OF THE MOTION SYSTEM RESPONSE

A final method of documentation involved application of software developed at Ames for measurement of the motion system responses. SAFE, for Six Axis Frequency Evaluation (Ref. B-6), applies a sum of sinewaves to all axes simultaneously, driving only the motion system. Output is in the form of magnitude and phase at the sinewave frequencies. Thus SAFE is a measure of the cab response only, and cannot be used to verify any other elements of the simulation. Still, it is valuable since, as mentioned earlier, the delays in the motion system represent significant unknowns.

SAFE was applied to the motion system during the simulation. The results are presented on Bode plots in Fig. B-8, where circles are magnitude and squares are phase angle at the 11 discrete input frequencies. Ideally, if the motion system had no mass or inertia, the frequency responses would have unity gain (0 Db) and zero phase at all frequencies. Instead, the linear responses show some attenuation (i.e., magnitudes less than 0 dB) and the angular responses have amplification (magnitude greater than 0 dB), with evidence of phase rolloff in all cases. The importance of these data, and the equivalent time-delay curves sketched on Fig. B-8, is discussed in the next section of this appendix.

F. ESTIMATES OF TIME DELAYS IN THE MOTION SYSTEM

Throughout this report the high-frequency response of the VMS motion system has been represented by a pure time delay. This is, in fact, a simplification based on analysis of the motion system from several sources, as documented here. The SAFE response data in Fig. B-8 suggest that the motion system could be much more accurately described by a combination of a high-frequency second-order lag, cascaded with a time delay element; the effects of such a model in the frequency range of piloted control, however, are not significantly different from that of a pure time delay, and hence it has been sufficient for the purposes of this report to use the simple approximation.

Frequency responses of the motion system, using signals generated by RSVP and analyzed in CIFER, are plotted in Fig. B-9. Additional points from the SAFE responses of Fig. B-8 have been included on Fig. B-9. These figures are the basis for the estimates of motion system delays; as a result, they are of great importance, and some time is required for their interpretation.

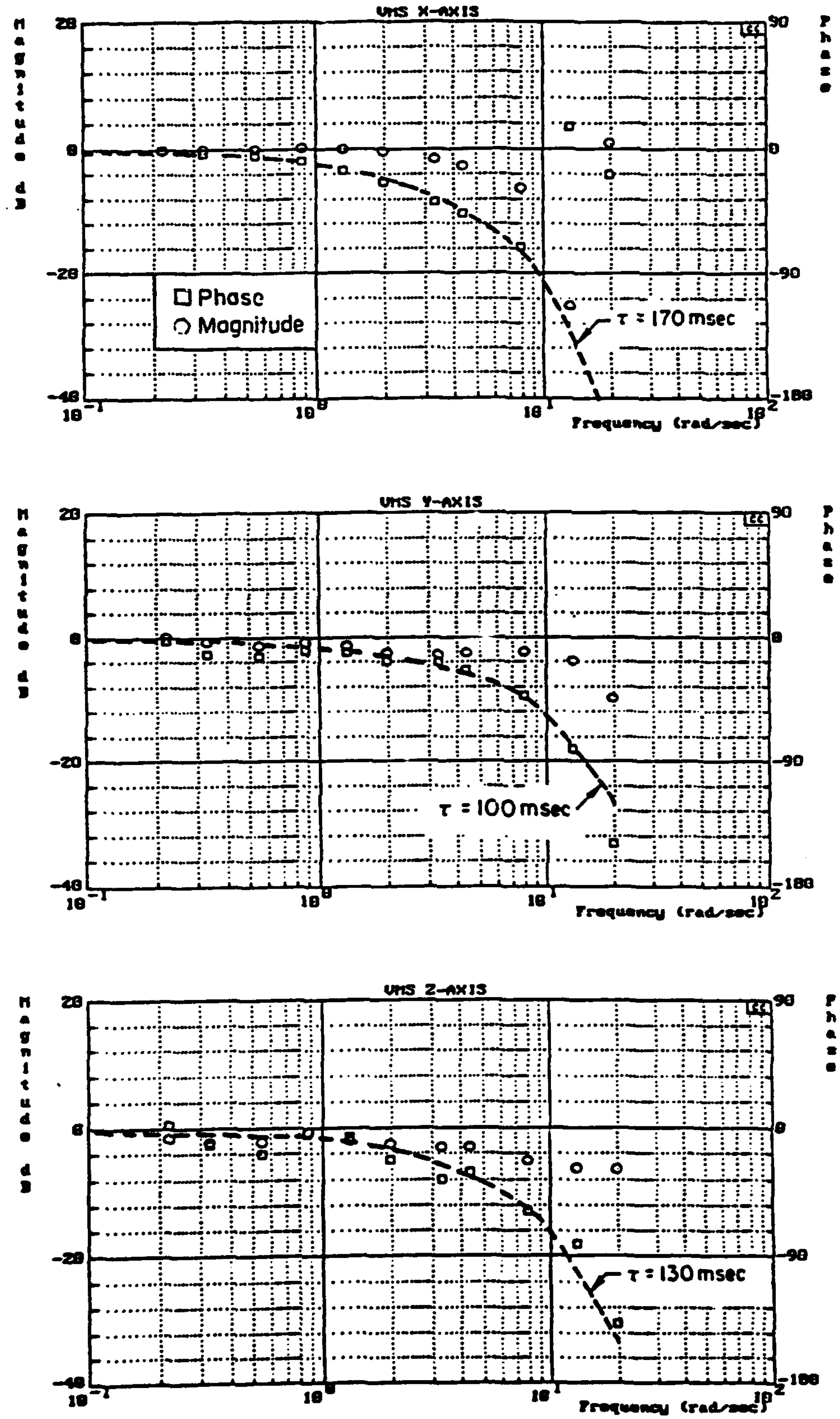


Figure B-8. Output Data from SAFE (Motion Position Followup/Motion Drive Position Command u_m/u_d)

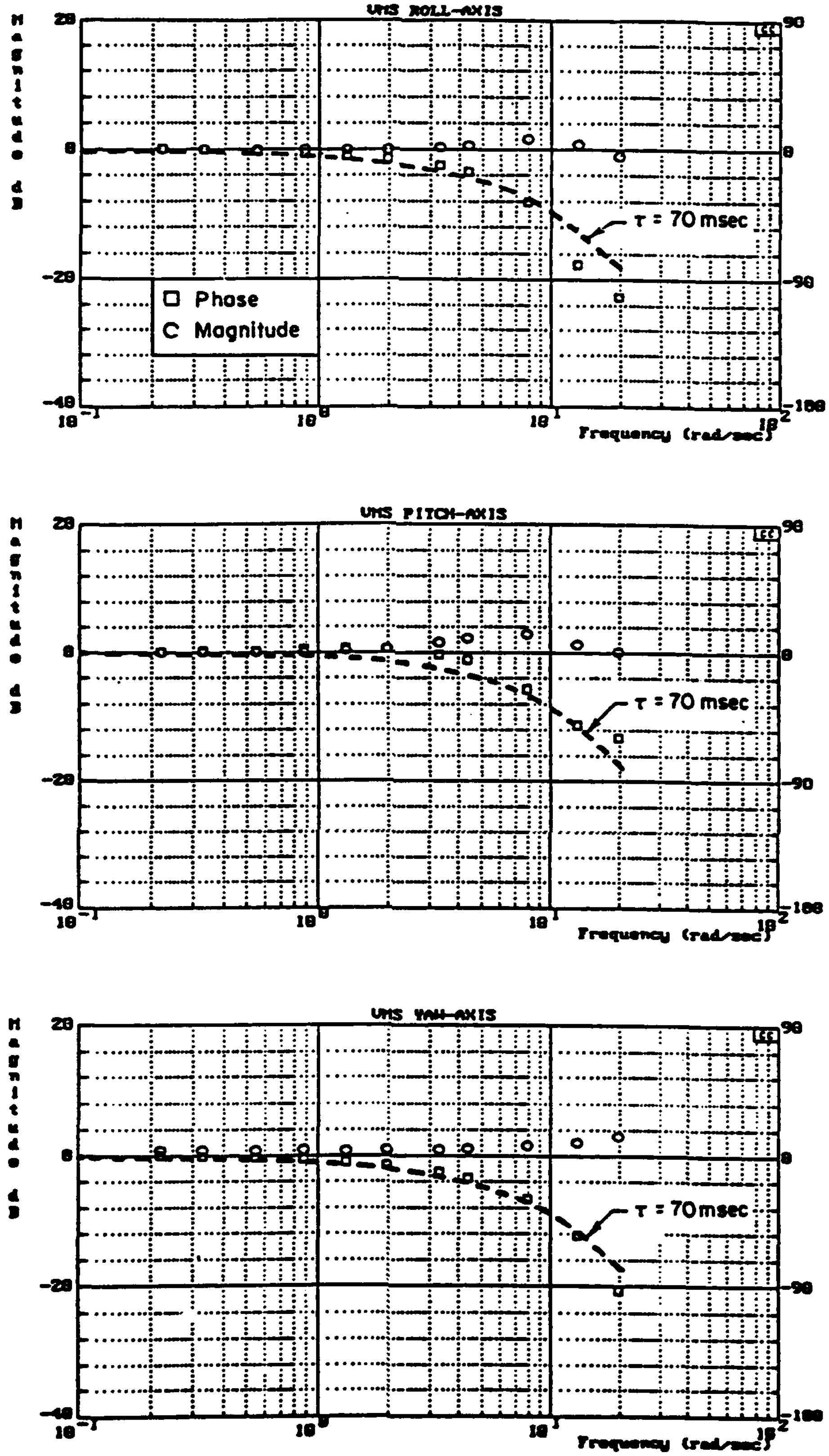
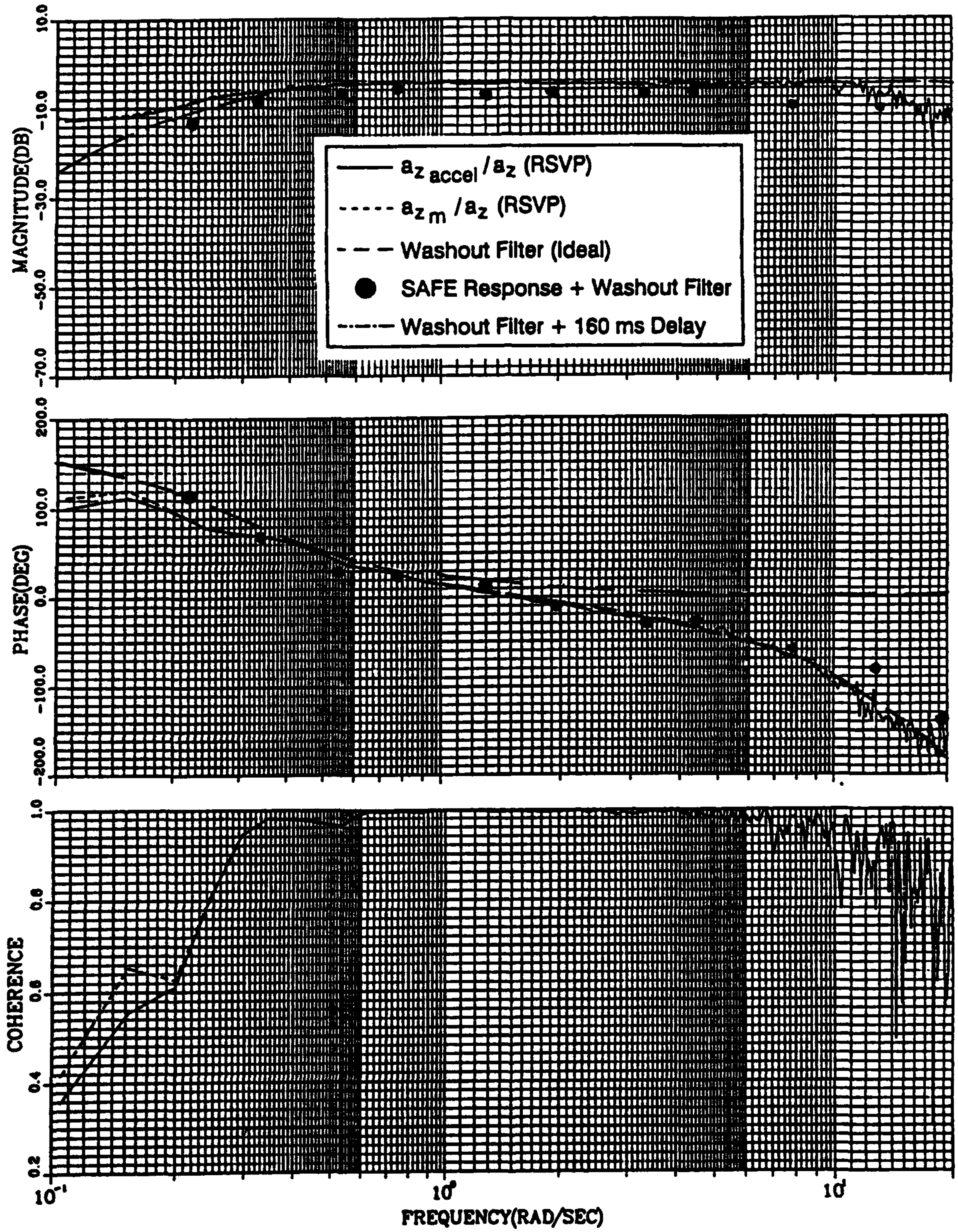
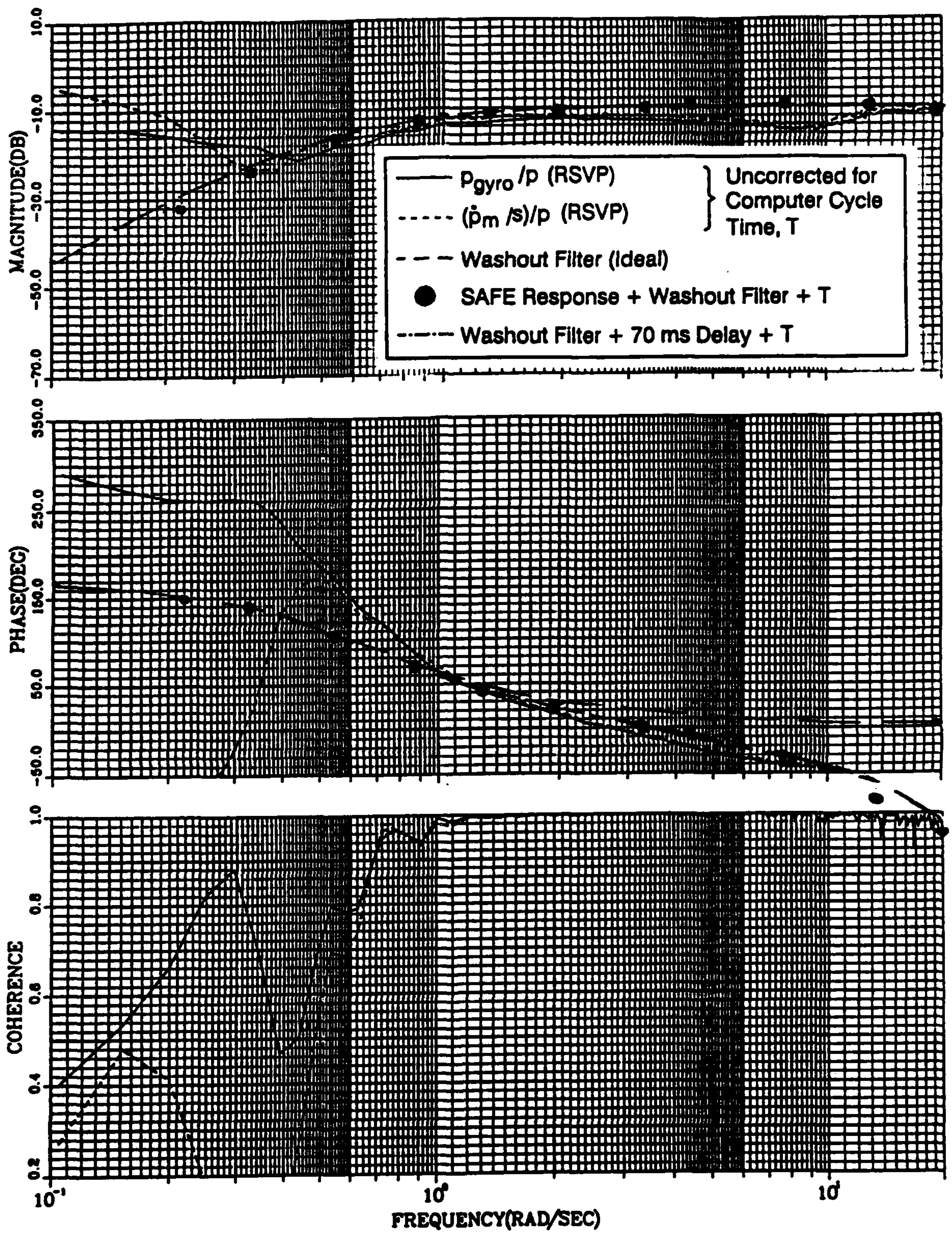


Figure B-8. (Concluded)



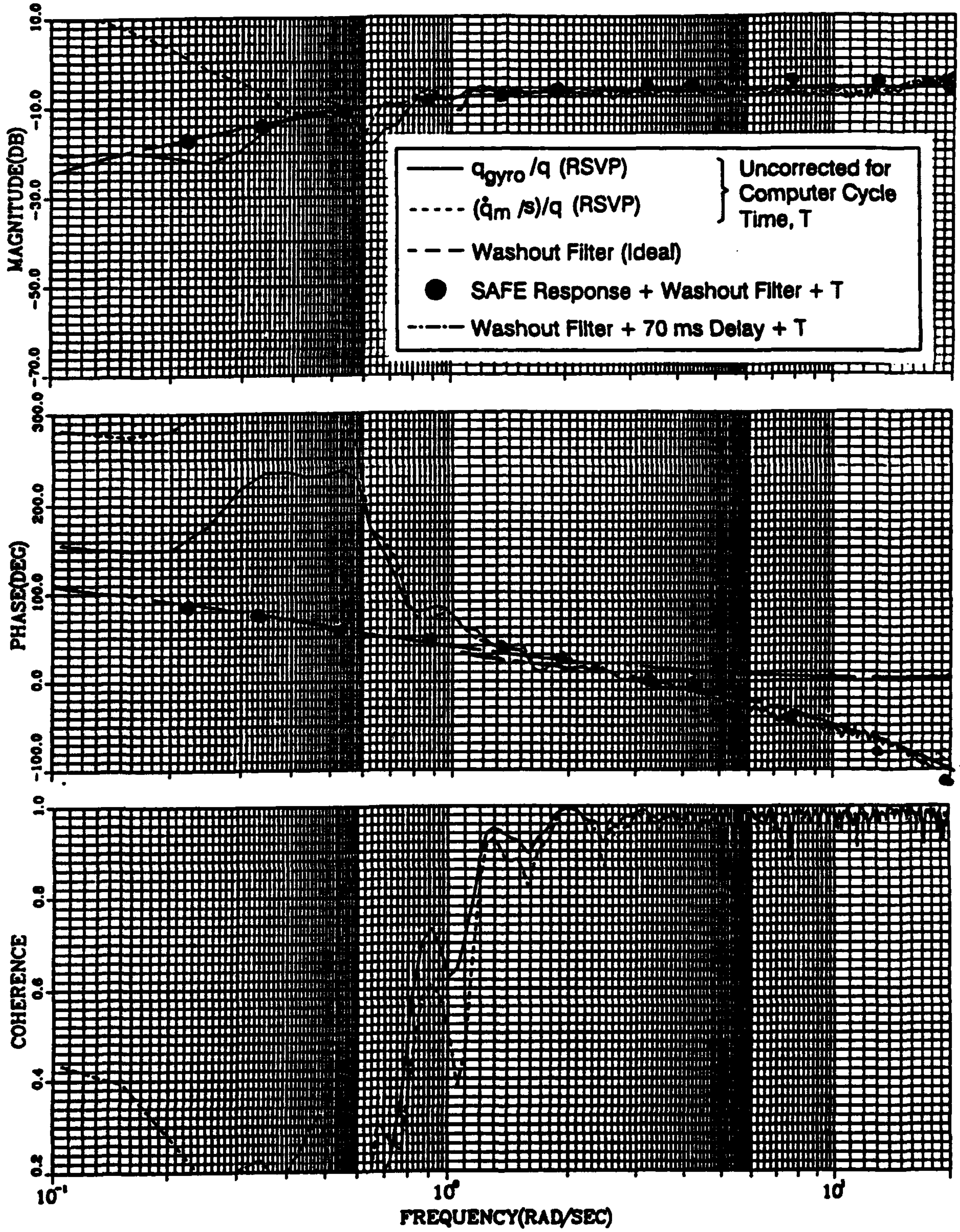
a) Vertical Acceleration

Figure B-9. Motion System Response Comparison from Cockpit-Mounted Gyros and Accelerometers, SAFE Responses, and Washout Filters



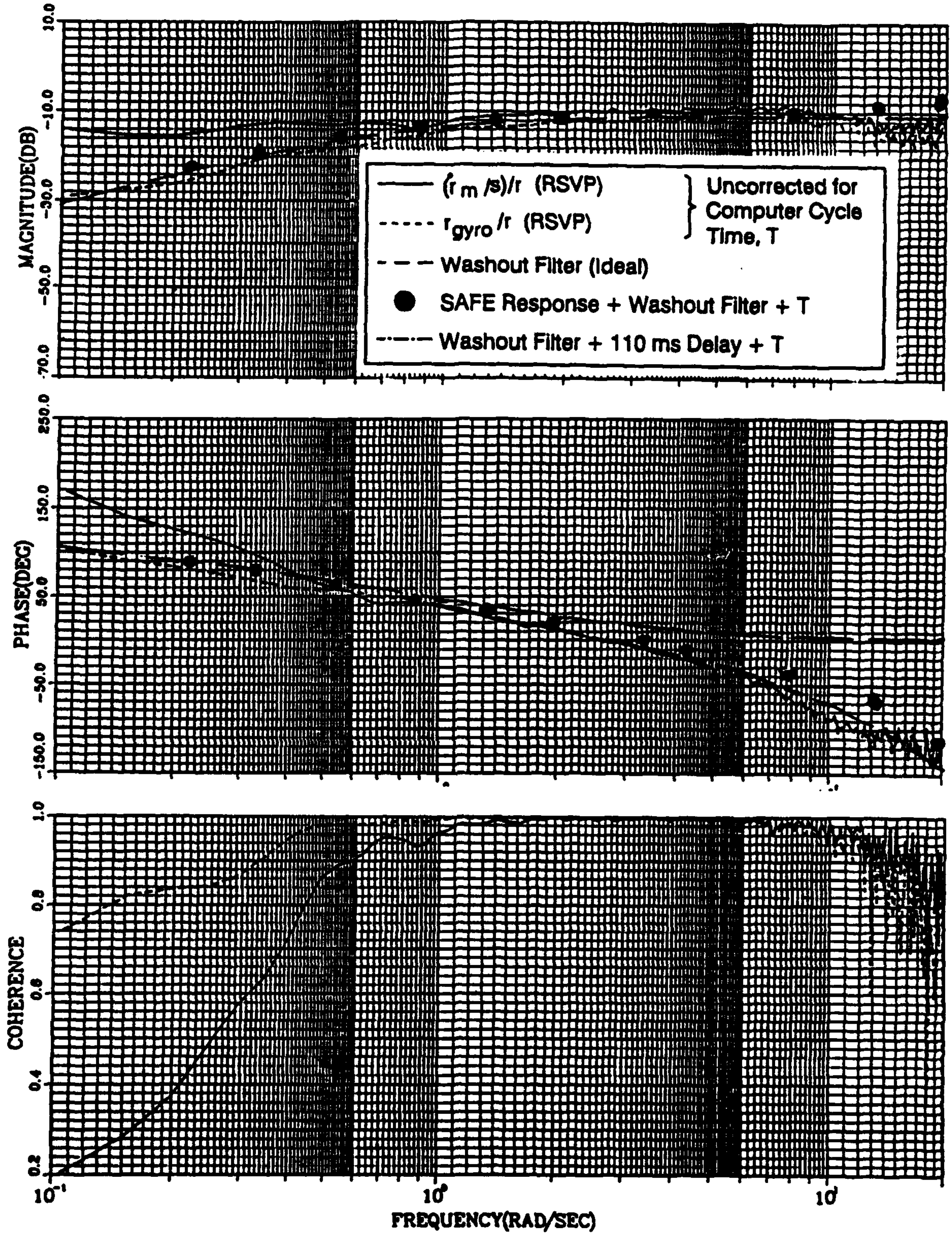
b) Roll Rate (Motion System Acceleration Response, $\dot{p}_m$, Resolved to Rate by Dividing by s)

Figure B-9. (Continued)



c) Pitch Rate (Motion System Acceleration Response, $\dot{q}_m$, Resolved to Rate by Dividing by s)

Figure B-9. (Continued)



d) Yaw Rate (Motion System Acceleration Response, $\dot{r}_m$, Resolved to Rate by Dividing by s)

Figure B-9. (Concluded)

The primary sources of data for Fig. B-9 were the RSVP-generated Gaussian-noise responses. These data were analyzed with CIFER to produce the responses of the add-on gyro/accelerometer package (subscripted "gyro" or "accel" in Fig. B-9) and of the resolved accelerations from the gimbal-mounted accelerometers (subscripted "m" for motion). The angular responses have been plotted in terms of angular rate; to do so, the gimbal accelerometer signals were divided by s. In all plots the "forcing function" is the response of the math model (the actual forcing-function command was, in all cases, the applied cockpit control for the appropriate axis of response). By referencing all signals to the math model, the frequency responses should, ideally, look much like the washout filter responses shown in Appendix A: low-frequency lead due to the washout, and a reduction in gain corresponding to the motion command gain. Deviations from this form are due to the dynamics of the VMS motion system.

Consider first the vertical acceleration response of Fig. B-9a. The coherence for this response is quite good down to about 0.25 rad/sec; the acceleration responses from the two separate sources (solid and short dashed lines) overlay almost perfectly, verifying the use of the resolved acceleration to represent cab response. Sketched on top of this figure (long dashed lines) are the gain and phase curves for the ideal washout filter, taken from Appendix A: this is what the responses <u>should</u> look like. In addition, the SAFE data from Fig. B-8 have been included for comparison. Since the SAFE data are for motion response/command, and hence do not include the washouts, these data had to be adjusted for the effects of the washout filter and motion gain for inclusion on Fig. B-9.

Comparison of the SAFE (solid points) and RSVP (solid and short dashed lines) data in Fig. B-9a shows some interesting differences: for example, there is a consistent shift in magnitudes that cannot be explained at this time. Note, however, that the sweep responses almost exactly overlay with the ideal washout filter response (long dashed lines). It is not known whether the amplitude attenuation suggested by SAFE actually exists. The phase data are in closer agreement, at least at the lower frequencies. SAFE suggests slightly lower phase rolloff (i.e., less delay) at the higher frequencies. For example, a reasonable fit to the SAFE phase data (Fig. B-8) is given by a time delay of 130 msec; as shown in Fig. B-9a, a delay of 160 msec is suggested by the RSVP data, since addition of this much delay to the ideal washout filter produces a response that almost exactly overlays the cab response (compare solid lines with dash/dot lines). It is not currently known why these sources of data differ by 30 msec; for this report it has been assumed that the RSVP data (for which coherence measures are available) are more reliable.

For the angular acceleration and rate response plots of Figs. B-9b through B-9d, the RSVP responses have not been corrected for computer cycle time. As mentioned above, computation of rates and positions in the simulation software included a one-cycle advancing integration. Since the input for the plots in Figs. B-9b through B-9d was angular rate of the math model, the responses

effectively include a one-cycle time delay that was not corrected for. Instead, a 20-msec delay was added to the SAFE responses to place them on a comparable time scale; effective time delay measures from these figures must thus have this 20-msec delay removed.

The roll and pitch responses (Figs. B-9b and B-9c) again show some discrepancy between the SAFE (solid dots) and RSVP (solid and short dashed lines) magnitude data. Phase curves, however, are very close, and as Figs. B-8 and B-9 show, the roll and pitch dynamics of the VMS motion system may be approximated by a pure time delay of 70 msec.

Phase responses for the yaw axis (Fig. B-9d) differ by a larger amount. The SAFE data (Fig. B-8) suggest an effective delay of 70 msec, while the RSVP results (Fig. B-9d) indicate a delay more on the order of 110 msec. Again, based on the confidence in the RSVP data, the latter number is assumed to be more appropriate.

It was not possible to get high-coherence frequency-response data for the final two degrees of freedom, surge (X) and sway (Y). Since there are no direct aircraft controllers in these axes, the responses are purely functions of coupling (i.e., translational response is generated by tilting), so it is to be expected that the correlation would not be high. Estimates of time delay based on the SAFE responses alone (Fig. B-8) are 170 msec for surge and 100 msec for sway.

Figure B-9 also serves to verify the measurement of rates and accelerations from cab-mounted accelerometers and tachometers. As described in Appendix C, two independent measures of angular rate and linear acceleration were obtained for this simulation. One was from resolved rate and accelerations that are regularly measured and monitored for all simulations on the VMS; the second came from a drop-in package installed in the cab for this simulation.

REFERENCES

B-1. McFarland, R. E., "Wrap-Around Tests," Informal Memorandum, July 1990.

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B-4. McFarland, Richard E., Transport Delay Compensation for Computer-Generated Imagery Systems, NASA TM 100084, Jan. 1988.

B-5. Tischler, Mark B., and Mavis G. Cauffman, "Frequency-Response Method for Rotorcraft System Identification with Applications to the BO-105 Helicopter," American Helicopter Society 46th Annual Forum Proceedings, May 1990, pp. 99-137.

B-6. Shirley, R. S., and A. D. Jones, "SAFE: Six Axis Frequency Evaluation of a Motion Simulator," AIAA Paper No. 73-932, Sept. 1973.

APPENDIX C

EXPERIMENT SETUP

APPENDIX C

EXPERIMENT SETUP

A. TASKS

Seven evaluation tasks were flown. The tasks were tailored to emphasize both precision and aggressiveness in hovering and low-speed flight. Figure C-1 illustrates the seven tasks and lists the requirements for desired and adequate performance. Not all tasks were flown for all configurations; the full scenario was used for evaluations of the competing sets of motion systems and for evaluation of the Usable Cue Environment, but most evaluations of time-delay effects were typically limited to the hover, vertical translation, slalom, and bobup/bobdown tasks, with other tasks occasionally added.

The pilots were given a written briefing of the simulation and details of the tasks. This briefing is included as the final section of this appendix.

B. PILOTS

Seven pilots participated in the simulation. Pilots D and T are with NASA Ames Research Center; Pilot S is an Army test pilot assigned to Ames; Pilots M and Mc are test pilots for the Army Airworthiness Qualification Test Directorate (formerly the Aviation Engineering Flight Activity), Edwards AFB, CA; Pilot G is a retired NASA pilot, now employed by an on-site contractor at Ames Research Center; and Pilot H is a contractor engineer/test pilot. Pilot D was the primary evaluator for all phases of the simulation. Pilots T and S participated primarily in the motion system evaluations. Technical difficulties with the VMS motion system limited evaluations by Pilot H to fixed-base only.

C. DATA RECORDING

The primary qualitative data taken during the simulation consisted of pilot ratings (both Handling Qualities Ratings and Visual Cue Ratings) and comments. The detailed ratings are tabulated in Appendix D and transcribed comments are given in Appendix E.

Quantitative data included time-history data on both stripcharts and magnetic tapes, and documentation of the various configurations through frequency response techniques. Online analysis was available through a program developed by NASA for the simulation; a description of this program and example results are given in Appendix B. Additional piloted frequency-sweep data were recorded and analyzed after the simulation, and these data are also discussed in Appendix B.

MANEUVERS	DESIRED PERFORMANCE	ADEQUATE PERFORMANCE
1 20 ft Hover (1 minute)		
Position	Keep Cone in Window	Cone in Window 50% of Time
Altitude	±2 ft	±5 ft
Heading	±5°	±10°
2 Vertical Translation		
Position	Same as Hover	Same as Hover
Altitude	Same as Hover	Same as Hover
Heading	Same as Hover	Same as Hover
3 Pirouettes		
Position	±10 ft	±20 ft
Altitude	±5 ft	±10 ft
Heading	Pointed at Center	Pointed at Center
Time	45 s	75 s
4 Slalom		
Position	Δy < 3 Squares	Don't Hit Poles
Airspeed	+3, -5 kts	-5 kts
Altitude	±15 ft	+30, -20 ft
5 Bobup/Down		
Altitude (Up)	±6 ft	±12 ft
Altitude (Down)	-5 ft	-10 ft
Time	12 s	18 s
6 Dash/Quickstop		
Position	Past last pole, before sidestep stripe	Past next to last pole, before sidestep stripe
Altitude	±15 ft	±25 ft
7 Sidestep		
Position	±20 ft	±28 ft
Altitude	±10 ft	±20 ft
Heading	±10°	±20°

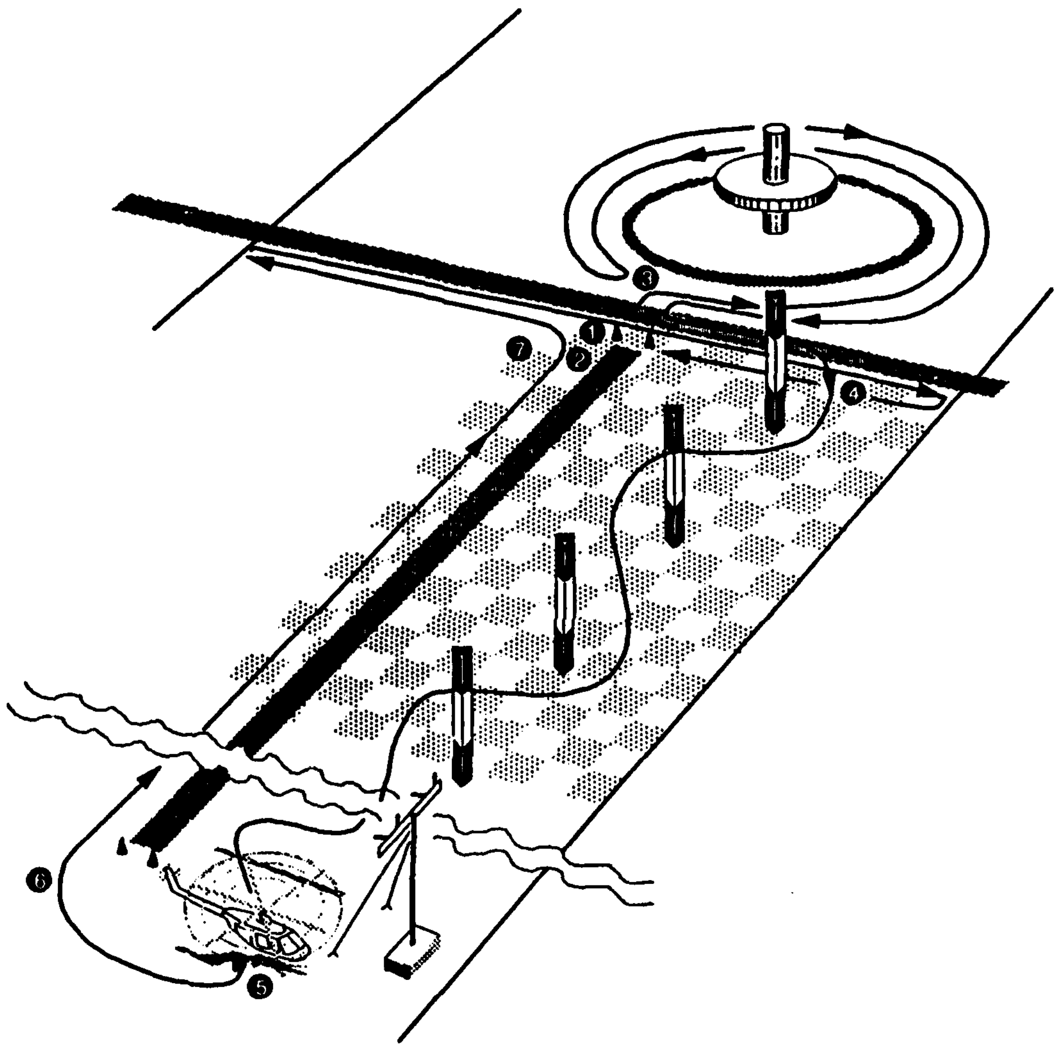

Figure C-1. Tasks

D. VERIFICATION OF MOTION RESPONSES

Responses of the VMS simulator cab are routinely measured by various tachometers and accelerometers mounted on the assembly. These responses are then resolved through software to represent the accelerations, rates, and attitudes sensed at the pilot's stations. There are, however, no measurement devices located physically at the pilot's station itself.

Because of the importance of accurately documenting the forces sensed by the pilot, a package of linear accelerometers and angular rate gyros was mounted in the cockpit directly behind the pilot's seat. The output of these devices was compared with the resolved accelerations and rates to verify the accuracy of the latter in representing the motion system responses. Comparison frequency responses from these two measurements are given in Appendix B.

E. PILOT BRIEFING

1. Introduction

The objective of this experiment is to quantify the effects of variations in motion system characteristics and delays in the visual system for aggressive and non-aggressive tasks. The motion system of the VMS will be set up to be representative of "normal operation," as well as with a modified set of gains based on frequency response measures. In addition, these results will be compared to fixed-base runs. The simulated rotorcraft will be a completely decoupled transfer function model with known Level 1 handling characteristics. The majority of the runs will be made with a Rate Response-Type, and a few runs will be made with an Attitude Response-Type. Piloted evaluations will be made for each set of motion gains, referred to as systems A, B, and C. Motion system A emphasizes the initial response, and allows out-of-phase motion at low frequencies, whereas system B maintains the phasing between the motion and model at the expense of the initial response. Motion system C is fixed-base. In addition, piloted evaluations will be made with systematic variations in the visual system time delay.

Two maneuver sets will be flown. The first series of tasks consists of moderately aggressive maneuvers, whereas the second set includes highly aggressive maneuvering. The motion gains will be set so that no limits are encountered, i.e., the motion gains will be tailored to the maneuvers.

You are being asked to evaluate the flying qualities of each visual/motion setup as if different rotorcraft were being simulated, using the standard Cooper-Harper handling qualities scale. In addition, your comments regarding the fidelity of the visual and motion system are being solicited (Table C-1). Some items to consider are:

TABLE C-?. PILOT COMMENT CARD

1. Is your flying technique modified because you are flying a simulator? Please explain?

2. Comment on the aircraft response - crisp? sluggish? any unusual characteristics?

3. How did the motion cues affect your control of the rotorcraft?

   — valuable for control

   — of some value, but not very realistic

   — no impact on control could be discerned

   — motion cues affected my ability to control the rotorcraft in a negative way

4. Compare this motion system with the other systems flown in this experiment.

5. Did the motion and visual cues seem consistent?

6. If there were any unusual, conflicting, or uncomfortable visual or motion cues, please describe them, and note which axis they occurred in.

7. Was there any feeling of discomfort, nausea, disorientation, or illness during the task? If so when did such symptoms occur, and how long did they last?

8. Please discuss any obvious deficiencies in the visual scene.

- Ability to maneuver with "hummingbird-like" precision and aggressiveness.

- Impressions related to motion cueing, e.g.,

  — valuable cue for rotorcraft control

  — Of some value, but not very realistic

  — No impact on rotorcraft control

  — Negative impact on rotorcraft control

- Any tendency towards physiological distress or feeling of malaise. If so, does it seem visually driven or a result of poor motion cueing.

- Compare the motion cueing of each system to the other two systems.

- Evaluate the visual scene using the Visual Cue Rating (VCR) rating scale.

2. Evaluation Maneuvers

The evaluations will be conducted over a test course which consists of a series of maneuvers as illustrated in Figure C-1. The experimental procedure will be to fly the test course two times for practice, and a third time for the formal evaluation. During the formal evaluation, the HQRs and VCRs should be given immediately after conducting each task. This can be accomplished by going to the initial condition mode on the simulator, or by simply sitting in hover during the rating process.

There is a red button below your right thumb on the cyclic stick. Please push this button at the beginning and end of each maneuver. This will reset the zero reference for performance measures on the strip chart recorders.

Each of the maneuvers is described below. The specified tolerances should be maintained <u>most</u> of the time. Momentary excursions are acceptable, as long as the errors are quickly corrected to bring the performance within tolerance. The maneuvers and desired performance limits are based on specification maneuvers in Section 4 of ADS-33C. In most cases certain minor adjustments have been made to either the maneuver definition or the desired performance limits. These changes have been made in an effort to better adapt the maneuvers to the specific visual references available on the CGI.

a. <u>Hover</u> (ADS-33C Para. 4.1.1, except 20kt wind removed)

Initiate the maneuver approximately 30 ft from the orange cone which will appear at the 1 o'clock position. The initial altitude will be 20 ft. Briskly move over to the traffic cone and maintain the cone at the bottom of the lower right window for one minute (clock with sweep second hand is above right knee).

- Desired Performance
  - Keep the cone within the lower half of the-window.
  - The cone should be reasonably stabilized, i.e., it should not be continuously wandering.
  - Maintain altitude within plus or minus 2 ft.
  - Maintain heading within plus or minus 5 deg.

- Adequate performance
  - Keep the cone within the window at least 50% of the time.
  - Maintain altitude within plus or minus 5 ft.
  - Maintain heading within plus or minus 10 deg.

b. Vertical Translation (surrogate for ADS-33C Para. 4.1.3)

Since it is not practical to make vertical landings on the simulator, a similar task has been defined using the orange cone as a ground reference. Starting at a radar altitude of 20 feet, execute a descent to 10 ft followed by a climb to 30 ft, and finally a descent back to 20 ft.

- Desired Performance
  - — Keep the cone within the lower half of the right window at all times.
  - — Achieve target altitudes within plus or minus 2 ft.
  - — Maintain heading within plus or minus 5 deg.

- Adequate Performance
  - — Keep the cone within the right window at least 50% of the time.
  - — Maintain heading within plus or minus 10 deg.

c. Pirouette (ADS-33C Para. 4.1.4)

Initiate the maneuver from a stabilized hover over a point on the circumference of the circle defined by the boundary between the red and yellow stripes, and with the nose of the rotorcraft pointed at the tower in the center of the circle. Because of the field-of-view of the simulator, it is not possible to hover directly over this line. Therefore, hover so that the line passes directly under the, instrument panel. The hover altitude shall be 20 ft. Accomplish a lateral translation around the circle, keeping the rotorcraft position at constant radius, and the nose pointed at the center of the circle. Perform the maneuver in both directions.

- Desired Performance
  - — Maintain the boundary between the red and yellow paths under the instrument panel. This corresponds to a plus or minus 10 ft position error.
  - — Maintain altitude so that you cannot see the top or bottom of the black and yellow disk. This corresponds to plus or minus 5 ft of altitude error (note that ADS-33C requires $\pm$ 3 ft).
  - — Maintain heading so that the nose of the helicopter is always pointed at the center of the circle.
  - — Complete the pirouette within 45 seconds.

- Adequate Performance
  - — Maintain the radial position within approximately 20 ft. (Note: each square on the ground is 14 feet on a side)
  - — Maintain altitude within plus or minus 10 ft.
  - — Complete the maneuver within 75 seconds.

d. Slalom (no specific counterpart in ADS-33C)

Fly a slalom maneuver around the black and white poles at a constant airspeed of 40 knots, and at an altitude of 20 ft.

- Desired Performance
  - Maintain the maximum lateral distance from the poles at less than three squares.
  - Maintain airspeed within plus 3 and minus 5 knots.
  - Maintain altitude within plus or minus 15 ft.

- Adequate Performance
  - Don't hit any poles.
  - Maintain airspeed above 35 kts.
  - Do not fly above the poles or hit the ground.

e. Bobup and Bobdown (ADS-33C Para. 4.2.3)

Initiate the maneuver from a 15 ft hover, pointed east in front of the crane, and at a fore-aft location so that the yellow stripe is to your left. Initiate a bobup to the hover board, and stabilize for approximately 3 seconds, followed by an immediate bobdown. Repeat the maneuver three times.

- Desired Performance
  - Complete each bobup/bobdown in no more than 12 seconds.
  - Maximum overshoot on bobup no more than 1/2 square on hover-board (this corresponds to an altitude tolerance of plus or minus 6 ft).
  - Maximum overshoot on bobdown no more than 5 feet.

- Adequate Performance
  - Complete bobup/bobdown in no more than 18 seconds.
  - Maximum overshoot on bobup no more than 1 square on hover-board.
  - Maximum overshoot on bobdown no more than 10 feet.

f. Quickstop (ADS-33C Para. 4.2.1)

Starting from a stabilized hover at the south end of the course, abeam the yellow bobup stripe, pitch down 10 deg to initiate an acceleration to 60 kts. Initiate the deceleration at the perpendicular yellow line just after the third pole to stop at the north end of the yellow stripe. Fly to one side of the stripe so that the end does not disappear during the deceleration. The reference altitude or this maneuver is 25 ft.

- Desired Performance
  - Complete the maneuver to arrive at a stabilized hover past the last pole, but before the red and yellow sidestep stripes.
  - Maintain altitude within plus or minus 15 ft.

- Adequate Performance
  - Complete the maneuver after the next to last pole, but prior to the red and yellow sidestep stripe.
  - Maintain altitude below the poles, and do not hit the ground.

g. <u>Sidestep</u> (similar to ADS-33C Para. 4.2.2)

Starting from a stabilized hover at the south end of the pirouette circle, with the instrument panel over a line formed by the intersection of the yellow and red stripes (oriented in an east-west direction), and with the rotorcraft heading north, initiate a brisk lateral translation to the right. The initial bank angle should be at least 20 degrees. Decelerate to a stabilized hover over the right edge of the grey pad, using at least 15 degrees of bank. Repeat this maneuver to the left edge of the grey pad, and then back to the center. Maintain an altitude of 20 ft.

- Desired Performance
  - Maintain the aircraft-fixed reference over the line formed by the intersection of the red and yellow stripes. This corresponds to plus or minus 20 ft.
  - Maintain altitude within plus or minus 10 ft.
  - Maintain heading within plus or minus 10 degrees.

- Adequate Performance
  - Maintain longitudinal position within plus or minus 28 ft.
  - Maintain altitude within plus or minus 20 ft.
  - Maintain heading within plus or minus 20 degrees.

APPENDIX D

PILOT RATINGS AND RUN LOGS

APPENDIX D

PILOT RATINGS AND RUN LOGS

A. PILOT RATINGS

Cooper-Harper Handling Qualities Ratings (HQRs, Ref. D-1) are given in Table D-1 and Visual Cue Ratings (VCRs, Ref. D-2) in Table D-2. As defined in Ref. D-2, VCRs are to be assigned by the pilots based on their ability to make aggressive and precise corrections in attitude, horizontal translational rate, and vertical translational rate. In some cases, however, the pilots in this simulation preferred to assign separate VCRs for pitch and roll attitude. For these cases the VCRs in Table D-2 are the worst (highest numerically) of the two.

The VCRs in Table D-2 were obtained for the high-Bandwidth Rate Response-Type, which was Level 1 by the requirements of ADS-33C and based on the HQRs. VCRs were sometimes taken for other configurations, including the high-Bandwidth Rate Response-Type with added time delay. These VCRs have not been tabulated here, but are included in the run logs (see below).

B. RUN LOGS

A listing of the run logs for the simulation is given in Table D-3. Run numbers were assigned by pilot, e.g., Runs 400 through 499 and 700 through 708 were assigned for to Pilot D. Therefore, while Table D-3 lists the runs sequentially by date, the run numbers are not sequential. Table D-3 the following:

- Configuration identifier (Table D-4); a second letter has been added to several of the configuration labels, to identify Low-Bandwidth (second letter L) and ACAH (second letter A) cases;

- Motion system (Appendix A):
  —— Fixed Base (F)
  —— Baseline Motion Washouts and Gains (B)
  —— Modified Motion Washouts and Gains (M);

- Task (Appendix C):
  —— Precision Hover (H)
  —— Vertical Translation (V)
  —— Pirouette (P)
  —— Slalom (Sl)
  —— Bobup/Bobdown (B)

—— Dash/Quickstop (Q)

—— Sidestep (Ss);

- HQR (HQ);

- VCRs (where assigned):

—— Pitch (Theta) and roll (Phi) attitudes

—— Horizontal translational rates (Xdot)

—— Vertical translational rates (Hdot).

TABLE D-1. HANDLING QUALITIES RATINGS

Configuration	Response-Type	Added Delay	Vis. Comp. Off (x)	Fixed Base (x)	Hover D	Hover G	Hover S	Hover	Hover T	Hover M	Hover Mc	Hover H	Avg. (Hov)	Vertical Transl. D	Vertical Transl. G	Vertical Transl. S	Vertical Transl.	Vertical Transl. T	Vertical Transl. M	Vertical Transl. Mc	Vertical Transl. H	Avg. (Transl)
B (Baseline)	Rate (Hi)	0			4	2	3		3	3	4		3.17	4.5	3	3		3	4.5	4		3.67
N		80			3						4		3.50	4						4		4.00
A		0	x		6		5			3	3		4.25	6		4			4	3		4.25
E		200								4			4.00						5			5.00
D		120	x		4.5				4				4.25	5				5				5.00
P		300	x		8								8.00	8								8.00
B (Low BW)	Rate (Lo)	0			5		4		3				4.00	4		5		4				4.33
A							4						4.00			4						4.00
N									4				4.00					4				4.00
E		200							5				5.00					6				6.00
D		120	x						3				3.00					3				3.00
B (ACAH)	ACAH	0			2.5	2							2.25	4	4							4.00
E		200			5	2							3.50	5	4							4.50
D		120	x		4								4.00	4								4.00
B (Mod. Motion)	Rate (Hi)	0				2	3	4	2				2.75		3	4	4	3				3.50
B (Baseline FB)		0		x	3	4	3	3		4.5	4	5	3.79	5	4	5	3		5	5	4.5	4.50
A		0	x	x	5.5		3					5	4.50	4.5		3					6	4.50
L		80	x	x			3						3.00			4						4.00
E		200		x	4.5		5					5	4.83	5.5		4					5.5	5.00
D		120	x	x	6							4.5	5.25	6							5.5	5.75
J		260		x	6								6.00	6								6.00
G		300		x	7.5							7	7.25	7							7.5	7.25
H		220	x	x			4.5						4.50			4.5						4.50
B (Low BW FB)	Rate (Lo)	0		x	5 5.5		3						4.50	6		3						4.50

TABLE D-1. (Continued)

Configuration	Response-Type	Added Delay	Vis. Comp. Off (x)	Fixed Base (x)	Pirouette D	G	S	T	M	Mc	H	Avg. (Pir)	Slalom D	G	S		T	M	Mc	H	Avg. (Slalom)
B (Baseline)	Rate (Hi)	0			3	3	4	3				3.25	3	3	5		2	4	4		3.50
N		80											3						4.5		3.75
A		0	x										4		6			3	3		4.00
E		200																3			3.00
D		120	x										3				3				3.00
P		300	x										4.5								4.50
B (Low BW)	Rate (Lo)	0					4					4.00	3		4		4				3.67
A															7						7.00
N																	4				4.00
E		200															4				4.00
D		120	x														3				3.00
B (ACAH)	ACAH	0			3	3						3.00	3	3							3.00
E		200											5.5	6							5.75
D		120	x										4.5								4.50
B (Mod. Motion)	Rate (Hi)	0				3	4	2.5				3.17		4	3		3				3.33
B (Baseline FB)		0		x		4	5		4.5	4.5		4.50	4	5	6	5		5	4.5		4.92
A		0	x	x							5.5	5.50	6		5					4	5.00
L		80	x	x											4						4.00
E		200		x									6		6						6.00
D		120	x	x									7								7.00
J		260		x									6								6.00
G		300		x									7								7.00
N		220	x	x											7						7.00
B (Low BW FB)	Rate (Lo)	0		x	2.5		5					3.75	3		3						3.00

TABLE D-1. (Continued)

Configuration	Response-Type	Added Delay	Vis. Comp. Off (x)	Fixed Base (x)	Bobup/down D	Bobup/down G	Bobup/down S	Bobup/down T	Bobup/down M	Bobup/down Mc	Bobup/down H	Avg. (BUBD)	Dash/Quickstop D	Dash/Quickstop G	Dash/Quickstop S	Dash/Quickstop T	Dash/Quickstop M	Dash/Quickstop Mc	Dash/Quickstop H	Avg. (QS)
B (Baseline)	Rate (Hi)	0			3	3	3	3	3	3		3.00	2.5	3	3	4				3.13
N		80			4.5					4.5		4.50								
A		0	x		4.5		3		3	4		3.63								
E		200							5.5			5.50								
D		120	x		7			5				6.00								
P		300	x		9							9.00								
B (Low BW)	Rate (Lo)	0			4.5		2	2				2.83								
A							3					3.00								
N								4				4.00								
E		200						4.5				4.50								
D		120	x					5				5.00								
B (ACAN)	ACAN	0			3	4						3.50	4.5	3						3.75
E		200			7	6						6.50								
D		120	x		5.5							5.50								
B (Mod. Motion)	Rate (Hi)	0				4	3	3				3.33		3	3	3				3.00
B (Baseline FB)		0		x		4	4		4	4.5		4.13		3	4		4	4.5		3.88
A		0	x	x							5	5.00							5	5.00
L		80	x	x																
E		200		x																
D		120	x	x																
J		260		x																
G		300		x																
H		220	x	x																
B (Low BW FB)	Rate (Lo)	0		x			4					4.00			3					3.00

TABLE D-1. (Concluded)

Configuration	Response-Type	Added Delay	Vis. Comp. Off (x)	Fixed Base (x)	Sidestep D	G	S	T	M	Mc	H	Avg. (SS)
B (Baseline)	Rate (Hi)	0			4.5	4	4	3				3.88
M		80										
A		0	x									
E		200										
D		120	x									
P		300	x									
B (Low BW)	Rate (Lo)	0										
A							7					7.00
N												
E		200										
D		120	x									
B (ACAH)	ACAH	0				4						4.00
E		200										
D		120	x									
B (Mod. Motion)	Rate (Hi)	0				4	5	3				4.00
B (Baseline FB)		0		x		5	4		5	5		4.75
A		0	x	x							4.5	4.50
L		80	x	x								
E		200		x								
D		120	x	x								
J		260		x								
G		300		x								
N		220	x	x								
B (Low BW FB)	Rate (Lo)	0		x			4					4.00

TABLE D-2. VISUAL CUE RATINGS

	Hover			Vertical Translation			Pirouette			Slalom			Bobup/Down			Dash/Quickstop			Sidestep		
	Att	Hor	Ver	Att	Hor	Ver	Att	Hor	Ver	Att	Hor	Ver	Att	Hor	Ver	Att	Hor	Ver	Att	Hor	Ver
PILOT D:																					
Rate (Hi BW) Fixed Base	2.5	3.5	2	3	3.5	2				3.5	2.5	2									
Rate (Hi BW) Baseline Motion	3.5	3.5	2	3	4	2.5	3.5	2.5	2	3.5	3	2.5	3.5	2.5	2	2	2.5	2.5	4	3	2.5
Rate (Hi BW) Modified Motion	4	3.5	2	3	2.5	2	4	2.5	2	3	3	3	2.5	2	4.5	4.5	2.5	2.5	4	3.5	3
PILOT G:																					
Rate (Hi BW) Fixed Base	1	1	1	1	1	1	1	1	1	3	1	2	1	1	1	5	1	1	1	1	1
Rate (Hi BW) Baseline Motion	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Rate (Hi BW) Modified Motion	1	1	1	2	2	1	1	1	1	2	1	1	2	3	1	2	1	3	1	1	3
PILOT S:																					
Rate (Hi BW) Fixed Base	3	4	3	3	4	3	3	4	4.5	3	4.5	4	3	3	4	3	2.5	4	3	3.5	4
Rate (Hi BW) Baseline Motion	2	3	---	3	4	3	3	4	3	2	3.5	3	2	3.5	3	3	3	4	3	4	4
Rate (Hi BW) Modified Motion	3	4.5	---	2	3	4															
PILOT T:																					
Rate (Hi BW) Fixed Base																					
Rate (Hi BW) Baseline Motion	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	---	1.5	1.5	1.5	1.5	1.5	3	3	1.5	2	1.5
Rate (Hi BW) Modified Motion	1	1	1	1	1	1.5	1	1.5	1.5	3	2	1	1.5	1.5	1	1	1.5	1.5	2	1.5	1
PILOT M:																					
Rate (Hi BW) Fixed Base	3	4	2.5	3.25	4	4.25	3.5	4	2.75	4	4	4.5	4.25	2.75	3.75	3	4	3.5	3.25	4	3.5
Rate (Hi BW) Baseline Motion	2.75	3.75	2.5	3.5	4	3				4	4	3.25	3	3.5	3.5						
Rate (Hi BW) Modified Motion																					
PILOT Mc:																					
Rate (Hi BW) Fixed Base	3.5	3.5	3	4	3.5	3.5	4	4	4	4	2.5	3	4	3.5	3.5	4	3.5	3.5	4	3.5	4
Rate (Hi BW) Baseline Motion	3	3	---	3	4	3.5				4	2.75	3.5	3.5	3	2.5						
Rate (Hi BW) Modified Motion																					
PILOT H:																					
Rate (Hi BW) Fixed Base																					
Rate (Hi BW) Baseline Motion																					
Rate (Hi BW) Modified Motion																					

NOTE:

Att = Attitude VCR
Hor = Horizontal Translational Rate VCR
Ver = Vertical Translational Rate VCR

TABLE D-3. RUN LOGS

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/3/90	114	Mc	B	F	H	4	3.5	3.25	3.5	3
8/3/90	115	Mc	B	F	V	5	3	4	3.5	3.5
8/3/90	116	Mc	B	F	P	4.5	4	3	3	3
8/3/90	117	Mc	B	F	Sl	4.5	4	2	2.5	3
8/3/90	118	Mc	B	F	B	4.5	4	4	3.5	3.5
8/3/90	119	Mc	B	F	Q	4.5	4	3	3.5	3.5
8/3/90	120	Mc	B	F	Ss	5	4	3.25	3.5	4
8/3/90	121	M	B	F	H	4.5	3	3	4	2.5
8/3/90	122	M	B	F	V	5	3.25	3.25	4	4.25
8/3/90	124	M	B	F	P	4.5	3.5	3.5	4	2.75
8/3/90	125	M	B	F	Sl	5	4	4	4	4.5
8/3/90	127	M	B	F	B	4	4.25	4.25	2.75	3.75
8/3/90	128	M	B	F	Q	4	3	3	4	3.5
8/3/90	129	M	B	F	Ss	5	3.25	3.25	4	3.5
8/6/90	200	S	B	F	H	3	3	3	4	3
8/6/90	201	S	B	F	P	5	3	3	4	4.5
8/6/90	202	S	B	F	V	5	3	3	4	3
8/6/90	203	S	B	F	Sl	6	3	3	4.5	4
8/6/90	204	S	B	F	B	4	3	3	3	4
8/6/90	205	S	B	F	Q	4	3	3	2.5	4
8/6/90	206	S	B	F	Ss	4	3	3	3.5	4
8/6/90	301	H	A	F	H	5				
8/6/90	302	H	A	F	V	6				
8/6/90	303	H	A	F	P	5.5				
8/6/90	304	H	A	F	Sl	4				
8/6/90	305	H	A	F	B	5				
8/6/90	306	H	A	F	Q	5				
8/6/90	307	H	A	F	Ss	4.5				
8/6/90	308	H	B	F	H	5				
8/6/90	309	H	B	F	V	4.5				
8/6/90	310	H	E	F	H	5				
8/6/90	311	H	E	F	V	5.5				
8/6/90	312	H	G	F	H	7				
8/7/90	313	H	G	F	V	7.5				
8/7/90	314	H	D	F	H	4.5				
8/7/90	314	H	D	F	V	5.5				

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/7/90	402	D	A	F	H					
8/7/90	403	D	A	F	H	5.5	3.5	3.5	4	2.5
8/7/90	404	D	A	F	V	4.5	3	3	4	4
8/7/90	406	D	A	F	SI	6	4	4	4.5	2
8/7/90	407	D	D	F	H	6	4	4	4	2
8/7/90	408	D	D	F	V	6	4	4	3	2
8/7/90	409	D	D	F	SI	7	4.5	4.5	4.5	2.5
8/7/90	410	D	B	F	H	3	2.5	2.5	3.5	2
8/7/90	411	D	B	F	V	5	3	3	3.5	2
8/7/90	412	D	B	F	SI	4	3.5	3.5	2.5	2
8/7/90	413	D	E	F	H	4.5	3.5	3.5	2.5	2
8/7/90	414	D	E	F	V	5.5	4	4	4	2.5
8/7/90	415	D	E	F	SI	6	3.5	3.5	4	2.5
8/7/90	416	D	G	F	H	7.5	5	5	3.5	3
8/7/90	417	D	G	F	V					
8/7/90	418	D	G	F	V	7	5	5	3	2.5
8/7/90	419	D	G	F	SI	7	3.5	3.5	5	3.5
8/7/90	420	D	J	F	H	6	3	3	4	4
8/7/90	421	D	J	F	V	6	4.5	4.5	4.5	4.5
8/7/90	422	D	J	F	SI	6	4	4	2.5	4
8/8/90	210	S	B	F	H	3				
8/8/90	211	S	B	F	V	3				
8/8/90	212	S	B	F	SI					
8/8/90	213	S	B	F	SI					
8/8/90	214	S	B	F	SI	5				
8/8/90	215	S	E	F	H	5				
8/8/90	216	S	E	F	V	4				
8/8/90	217	S	E	F	SI	6				
8/8/90	218	S	A	F	H	3				
8/8/90	219	S	A	F	V	3				
8/8/90	220	S	A	F	SI	5				
8/8/90	221	S	L	F	H	3				
8/8/90	222	S	L	F	V					
8/8/90	223	S	L	F	V	4				
8/8/90	224	S	L	F	SI					
8/8/90	225	S	L	F	SI	4				
8/8/90	226	S	H	F	H	4.5				

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/8/90	227	S	H	F	V	4.5				
8/8/90	228	S	H	F	Sl	7				
8/9/90	230	S	BL	F	H	3				
8/9/90	231	S	BL	F	V					
8/9/90	232	S	BL	F	V	3				
8/9/90	233	S	BL	F	P					
8/9/90	234	S	BL	F	P	5				
8/9/90	235	S	BL	F	Sl					
8/9/90	236	S	BL	F	Sl	3				
8/9/90	237	S	BL	F	B					
8/9/90	238	S	BL	F	B	4				
8/9/90	239	S	BL	F	Q					
8/9/90	240	S	BL	F	Q	3				
8/9/90	241	S	BL	F	Ss					
8/9/90	242	S	BL	F	Ss					
8/9/90	243	S	BL	F	Ss					
8/9/90	244	S	BL	F	Ss					
8/9/90	245	S	BL	F	Ss	4				
8/9/90	430	D	BL	F	H	5				
8/9/90	431	D	BL	F	V	6				
8/9/90	432	D	BL	F	Sl					
8/9/90	433	D	BL	F	Sl	3				
8/9/90	434	D	BL	F	H	5.5				
8/9/90	435	D	BL	F	P	2.5				
8/9/90	501	G	B	F	H	4	1	1	1	1
8/9/90	502	G	B	F	V	4	1	1	1	1
8/9/90	503	G	B	F	P	4	1	1	1	1
8/9/90	504	G	B	F	Sl					
8/9/90	505	G	B	F	Sl	5	3	3	1	2
8/9/90	506	G	B	F	B	4	1	1	1	1
8/9/90	507	G	B	F	Q	3	5	5	1	1
8/9/90	508	G	B	F	Ss					
8/9/90	509	G	B	F	Ss	5	1	1	1	1
8/13/90	440	to 456 deleted; incorrect motion system								
8/14/90	462	D	B	B	H	4	3.5	3.5	3.5	2

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/14/90	463	D	B	B	V	4.5	3	3	4	2.5
8/14/90	510	G	B	B	H					
8/14/90	511	G	B	B	H					
8/14/90	512	G	B	B	H	2	1	1	1	1
8/14/90	513	G	B	B	V	3	1	1	1	1
8/14/90	514	G	B	B	P	3	1	1	1	1
8/14/90	515	G	B	B	Sl	3	1	1	1	1
8/14/90	516	G	B	B	B	3	1	1	1	1
8/14/90	517	G	B	B	Q	3	1	1	1	1
8/14/90	518	G	B	B	Ss	4	1	1	2	2
8/15/90	613	T	B	B	H	3	1.5	1.5	1.5	1.5
8/15/90	614	T	B	B	V	3	1.5	1.5	1.5	1.5
8/15/90	615	T	B	B	P	3	1.5	1.5	1.5	1.5
8/15/90	616	T	B	B	Sl	2	1.5	1.5	-	1.5
8/15/90	617	T	B	B	B	3	1.5	1.5	1.5	1.5
8/15/90	618	T	B	B	Q	4	1.5	1.5	3	3
8/15/90	619	T	B	B	Ss	3	1.5	1.5	2	1.5
8/16/90	133	M	B	B	H	3	2.75	2.75	3.75	2.5
8/16/90	134	M	B	B	V	4.5	3.5	3	4	3
8/16/90	135	M	B	B	Sl	4	3.5	2.75	4	3.25
8/16/90	136	M	E	B	H					
8/16/90	137	M	E	B	H	4	2.25	2.25	2.75	3
8/16/90	138	M	E	B	V	5	2.75	2.75	3.25	3.25
8/16/90	139	M	E	B	Sl	3	2	2.5	3.25	3
8/16/90	140	M	E	B	B	5.5	2.75	2.75	3	2.75
8/16/90	144	Mc	B	B	H	4	3	3	3	-
8/16/90	145	Mc	B	B	V	4	3	3	4	3.5
8/16/90	146	Mc	B	B	Sl					
8/16/90	147	Mc	B	B	Sl					
8/16/90	148	Mc	B	B	Sl	4	4	2.75	2.75	3.5
8/16/90	149	Mc	B	B	B	3	-	3.5	3	2.5
8/16/90	150	M	B	B	B	3	3	3	3.5	3.5
8/16/90	152	M	A	B	H	3	3.25	2.5	3.5	-
8/16/90	153	M	A	B	V	4	3.5	3	3.25	3.25
8/16/90	154	M	A	B	Sl	3	2.75	2.75	3.5	3.25
8/16/90	155	M	A	B	B	3	3	3	3.25	3.5

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/16/90	157	Mc	A	B	H	3	2.5	2.5	2.5	-
8/16/90	158	Mc	A	B	V	3	2.5	2.5	2.5	3
8/16/90	159	Mc	A	B	Sl	3	3	2.25	2	3
8/16/90	160	Mc	A	B	B	4	-	-	-	3
8/16/90	162	Mc	N	B	H	4	3.25	3.25	3.5	3.5
8/16/90	163	Mc	N	B	V	4	3.5	3.5	3.75	3.25
8/16/90	164	Mc	N	B	Sl					
8/16/90	165	Mc	N	B	Sl					
8/16/90	166	Mc	N	B	Sl	4.5	3.5	3	3	4
8/16/90	167	Mc	N	B	B					
8/16/90	168	Mc	N	B	B	4.5	-	-	3.5	3.5
8/16/90	250	S	B	B	H	3	2	2	3	-
8/16/90	252	S	B	B	V	3	3	3	4	3
8/16/90	253	S	B	B	P	4	3	3	4	3
8/16/90	255	S	B	B	Sl	5	2	2	3.5	3
8/16/90	256	S	B	B	B	3	2	2	3.5	3
8/16/90	257	S	B	B	Q					
8/16/90	258	S	B	B	Q	3	3	3	3	4
8/16/90	259	S	B	B	Ss					
8/16/90	260	S	B	B	Ss	4	3	3	4	4
8/16/90	465	D	B	B	P	3	3.5	3.5	2.5	2
8/16/90	466	D	B	B	Sl					
8/16/90	467	D	B	B	Sl	3	3.5	3.5	3	2.5
8/16/90	468	D	B	B	B	3	3.5	3.5	2.5	2
8/16/90	469	D	B	B	Q	2.5	2	2	2.5	2.5
8/16/90	470	D	B	B	Ss	4.5	4	4	3	2.5
8/16/90	520	G	B	M	H	2	1	1	1	1
8/16/90	521	G	B	M	V	3	2	2	2	1
8/16/90	522	G	B	M	P	3	1	1	1	1
8/16/90	523	G	B	M	Sl					
8/16/90	524	G	B	M	Sl	4	2	2	1	1
8/16/90	525	G	B	M	B	4	2	2	3	1
8/16/90	526	G	B	M	Q	3	2	2	1	3
8/16/90	528	G	B	M	Ss	4	1	1	1	3
8/17/90	261	S	B	M	H					
8/17/90	262	S	B	M	H	4	3	3	4.5	-
8/17/90	263	S	B	M	V	4	2	2	3	4

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/17/90	265	S	AL	B	H	5				
8/17/90	266	S	AL	B	V	4				
8/17/90	267	S	AL	B	SI					
8/17/90	268	S	AL	B	SI	6				
8/17/90	269	S	AL	B	B	3				
8/17/90	270	S	AL	B	Q	4				
8/17/90	471	D	AL	B	H	7				
8/17/90	472	D	AL	B	V	6				
8/17/90	473	D	AL	B	SI					
8/17/90	474	D	AL	B	SI	4				
8/17/90	475	D	AL	B	B	4.5				
8/17/90	476	D	BL	B	H	5				
8/17/90	477	D	BL	B	V	4				
8/17/90	478	D	BL	B	SI	3				
8/17/90	479	D	BL	B	B	4.5				
8/17/90	480	D	N	B	H	3				
8/17/90	481	D	N	B	V	4				
8/17/90	482	D	N	B	SI	3				
8/17/90	620	T	B	M	H	2	1	1	1	1
8/17/90	621	T	B	M	V	3	1	1	1.5	1.5
8/17/90	622	T	B	M	P					
8/17/90	623	T	B	M	P	2.5	1	1	1.5	1.5
8/17/90	624	T	B	M	SI	3	3	3	2	1
8/17/90	625	T	B	M	B	3	1.5	1.5	1.5	1
8/17/90	626	T	B	M	Q	3	1	1	1.5	1.5
8/17/90	627	T	B	M	Ss	3	2	2	1.5	1
8/17/90	630	T	BL	B	H	3				
8/17/90	631	T	BL	B	V	4				
8/17/90	632	T	BL	B	SI					
8/17/90	633	T	BL	B	SI	4				
8/17/90	634	T	BL	B	B	2				
8/17/90	636	T	NL	B	H	4				
8/17/90	637	T	NL	B	V	4				
8/17/90	638	T	NL	B	SI	4				
8/17/90	639	T	NL	B	B	4				
8/20/90	271	S	A	B	H	4				
8/20/90	272	S	A	B	V	4				

TABLE D-3. (Continued)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/20/90	273	S	A	B	SI	7				
8/20/90	274	S	A	B	B	3				
8/20/90	275	S	A	B	Ss	7				
8/20/90	276	S	B	M	H	3				
8/20/90	277	S	B	M	V					
8/20/90	278	S	B	M	V	4				
8/20/90	483	D	N	B	B	4.5				
8/20/90	484	D	D	B	H	4.5				
8/20/90	485	D	D	B	V	5				
8/20/90	486	D	D	B	SI	3				
8/20/90	487	D	D	B	B	7				
8/20/90	488	D	P	B	H	8				
8/20/90	489	D	P	B	V	8				
8/20/90	490	D	P	B	SI	4.5				
8/20/90	491	D	P	B	B	9				
8/20/90	493	D	BA	B	H	2.5				
8/20/90	494	D	BA	B	V	4				
8/20/90	495	D	BA	B	P	3				
8/20/90	496	D	BA	B	SI	3				
8/20/90	497	D	BA	B	B	3				
8/20/90	498	D	BA	B	Q	4.5				
8/20/90	640	T	EL	B	H	5				
8/20/90	641	T	EL	B	V	6				
8/20/90	642	T	EL	B	SI	4				
8/20/90	643	T	EL	B	B	4.5				
8/20/90	644	T	D	B	H	4				
8/20/90	645	T	D	B	V	5				
8/20/90	646	T	D	B	SI	3				
8/20/90	647	T	D	B	B	5				
8/20/90	648	T	DL	B	H	3				
8/20/90	649	T	DL	B	V	3				
8/20/90	650	T	DL	B	SI	3				
8/20/90	651	T	DL	B	B	5				
8/20/90	700	D	DA	B	H	4				
8/21/90	279	S	B	M	P	4				
8/21/90	280	S	B	M	SI	3				
8/21/90	281	S	B	M	B					

TABLE D-3. (Concluded)

Date	Run#	Pilot	Config.	Motion	Task	HQR	Theta	Phi	Xdot	Hdot
8/21/90	282	S	B	M	B	3				
8/21/90	283	S	B	M	Q	3				
8/21/90	284	S	B	M	Ss					
8/21/90	285	S	B	M	Ss	5				
8/21/90	286	S	BL	B	H	4				
8/21/90	287	S	BL	B	V	5				
8/21/90	288	S	BL	B	P	4				
8/21/90	289	S	BL	B	Sl	4				
8/21/90	290	S	BL	B	B	2				
8/21/90	530	G	BA	B	H	2	1	1	1	1
8/21/90	531	G	BA	B	V	4	2	2	2	2
8/21/90	532	G	BA	B	P	3	1	1	1	1
8/21/90	533	G	BA	B	Sl	3	2	2	1	2
8/21/90	534	G	BA	B	B	4	3	3	3	2
8/21/90	535	G	BA	B	Q	3	2	2	2	3
8/21/90	536	G	BA	B	Ss	4	1	1	2	3
8/21/90	537	G	EA	B	H	2				
8/21/90	538	G	EA	B	V					
8/21/90	539	G	EA	B	V	4				
8/21/90	540	G	EA	B	Sl	6				
8/21/90	541	G	EA	B	B	6				
8/21/90	701	D	DA	B	V	4				
8/21/90	702	D	DA	B	Sl	4.5				
8/21/90	703	D	DA	B	B	5.5				
8/21/90	704	D	EA	B	H					
8/21/90	705	D	EA	B	H	5				
8/21/90	706	D	EA	B	V	5				
8/21/90	707	D	EA	B	Sl	5.5				
8/21/90	708	D	EA	B	B	7				

TABLE D-4. CONFIGURATION IDENTIFIERS FOR RUN LOGS

Configuration	Response-Type	Added Delay (msec)	Vis. Comp. Off (x)	Fixed Base (x)
B (Baseline)	Rate (Hi)	0		
N		80		
A		0	x	
E		200		
D		120	x	
P		300	x	
BL (Low BW)	Rate (Lo)	0		
AL		0	x	
NL		80		
EL		200		
DL		120	x	
BA (ACAH)	ACAH	0		
EA		200		
DA		120	x	
B (Mod. Motion)	Rate (Hi)	0		
B (Baseline FB)		0		x
A		0	x	x
L		80	x	x
E		200		x
D		120	x	x
J		260		x
G		300		x
H		220	x	x
BL (Low BW FB)	Rate (Lo)	0		x

REFERENCES

D-1. Cooper, George E., and Robert P. Harper, Jr., The Use of Pilot Ratings in the Evaluation of Aircraft Handling Qualities, NASA TN D-5153, Apr. 1969.

D-2. Handling Qualities Requirements for Military Rotorcraft, ADS-33C, Aug. 1989.

APPENDIX E

TRANSCRIBED PILOT COMMENTS (LISTED BY PILOT)

APPENDIX E

TRANSCRIBED PILOT COMMENTS

A. ORGANIZATION OF COMMENTS

The pilot comments in this appendix have been sorted by pilot and then by run number. Run numbers were generally assigned by hundreds to each pilot; for example, run numbers in the 400's indicate runs made only by Pilot D. In some cases, a pilot made more than one hundred runs and a new "block" of numbers was assigned; for example, runs for Pilot D also include numbers in the 700's.

Comments have been transcribed from audio tapes and edited slightly for clarity and brevity.

B. PILOT D

Configuration A (Fixed Base)

Runs 402 and 403 (Hover). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I would say that there were moderately objectionable to very objectionable deficiencies and give it a 5-1/2. I didn't really feel like I could maintain my ground position within the parameters. I don't know how far I drifted away from it, but it felt like it required quite intense effort to keep a spot over the ground. Also, the control system was very susceptible to PIO, especially in roll. I noticed there was one point near the end of the task, after 45 seconds, where I had a tendency to really get behind in my control inputs and I could feel the PIO development. You couldn't stare at the cone to hover due to the system. It would really start rolling and pitching, so you had to use some point out on the horizon to maintain your hover. Using those cones in that position, you can't use the pirouette tower to hover on. In altitude, it seemed like it was fairly controllable, and very positively damped.

[For the VCRs,] I would say that the attitudes were probably a 3-1/2, fair to poor. Like I said, it did have a tendency after I went through the path to wander, and be conducive to PIO. Horizontal translational rate, it did wander a little bit. It felt like it wandered in fore and aft across the ground. Not so much lateral movement at the beginning, but at the very end the lateral movement did come in to it, and due to the rates that were developed and the slowness of the rates I will give it a 4 as far as positional cue reference. Vertical translational rate, I would give a 2-1/2 on that. There was a slight tendency to PIO on it, but still I was able to maintain it fairly well.

Run 404 (Vertical Translation). Was it controllable? Yes. Was adequate performance attained with tolerable pilot workload? Yes. Was it satisfactory without improvement? No. Minor but annoying deficiencies. I'm not sure that desired performance was met. I'd have to look at the numbers. I'd say that it's probably a 4-1/2. I thought it was pretty close to desired performance.

The VCRs: Attitude control was fair, a 3. Horizontal translational rate, I noticed that the rates once they were established were very stable around that point. It was a matter of just getting the kind of rate that you wanted to establish, and translating across the ground as you came down upon the cone, and the same thing with the vertical rate. You could ride right in and out on that line.

I would give horizontal translational rate a fair, and the vertical translational rate a fair. I guess there's really two tasks here. One is moving in on the cones, and then hovering over the cones. Taking it as a factor of hovering next to the cones that would drop it down to a 4 for horizontal translational rate. Vertical you could still maintain fairly well, and give that a 4.

Run 406 (Slalom). Is it controllable? Yes. Is adequate performance attained with tolerable pilot workload? Yes. Is it satisfactory without improvement? No. It seems like very objectionable, but tolerable deficiencies. Adequate performance required extensive pilot compensation.

VCR's: Attitude control, it was fair to poor, I give it a 4. Horizontal translational rate, It was difficult to maintain the 35 knots going down. Give that a 4-1/2. I noticed that airspeed has a tendency to climb away. Vertical translational rate was okay, give that a 2, it's pretty easy to maintain vertical translational rate.

Configuration D (Fixed Base)

Run 407 (Hover). Was it controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. Very objectionable but tolerable deficiencies. Adequate performance required extensive pilot compensation, a 6. What I noticed on this, it seemed like it took a real long time to notice the effect of the helicopter to the control input. It seemed to be quite a long delay, and then you didn't really know how long to leave it in for to get the desired output. Vertical axis was very controllable, and very easily maintained. You didn't even have to move the collective.

Okay, VCR's: Attitude cues, give it a 4. Horizontal translational rate, give that a 4. Vertical translational rate, a 2.

Run 408 (Vertical Translation). Was it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Very objectionable but tolerable deficiencies. Adequate performance required extensive pilot compensation. Give that a 6. It looked like the roll inputs on it were not very precise. It really had a tendency to PIO. There was a delay in seeing the resulting translational rate develop. You were constantly fighting it as you tried to move in on the cone. Once you were established real tight on the cone down at the 10-foot hover, it was very difficult to maintain the position over the ground so your translational rates develop. I noticed that they were mostly laterally, and consequently there was a tendency to PIO. Pitch attitudes were a little disconcerting at times because of the oscillations that were both in pitch and roll. Even though there weren't any large translational rates that develop until later, this was a little disconcerting because you thought you were going almost uncontrollable. You were trying to correct for that when it was really probably a PIO that was developing that you can cure by freezing on the stick.

VCR's: Attitude, a 4 due to the oscillation that you had around the neutral point that was difficult to control. The horizontal translational rate, make that a 3. It was fair because the precision was only fair, but you could make limited "X" corrections on the thing. Vertical translation, make that a 2. It was very controllable, and you could make precise corrections, and hold the altitude that you needed.

Run 409 (Slalom). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? No. I'd say major deficiencies, requires improvement. Adequate

performance not attainable. Maximum tolerable pilot compensation, a 7. The big thing on that, it did feel like it was controllable as we went through the pylons. We just didn't feel like we were totally in control of the helicopter as we went around the pylons. I couldn't adequately maintain a ground path in between the pylons. It seemed like it wanted to slip to the side, and noticed that due to the delay in reaction after control input, it was very disconcerting, and had a tendency to PIO. Airspeed control was difficult to maintain. Especially there at the beginning, when you needed to make fine little pitch adjustments to maintain your airspeed. There was more of a tendency for airspeed excursions with the pylons being close together there at the beginning. At the end, you were concerned with making a ground track, and airspeed had a tendency to go high. I think it even went out of the adequate as far as going better than the 8-knots, so that's the reason for the 7.

The VCR's: Attitude control was a 4-1/2, poor. You couldn't maintain the attitude that you were trying to command. Horizontal translational rate was a 4-1/2, fair to poor. Again, it was difficult trying to maintain the particular ground path that you wanted. Vertical translational rate was probably a 2-1/2. It felt like that was fairly easy to maintain, and it didn't have the tendency to exceed the 20-foot parameter that we have.

Baseline Configuration (Fixed Base)

Run 410 (Hover). Was it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. I'd say it was fair, some minor unpleasant deficiencies. Normal pilot compensation required for this desired performance. The big thing I noticed here, instead of it being translational-lateral problems, it seemed it was more of a pitch and fore and aft translational problems. Again, altitude was easy to hold, and as I said the roll was easy to hold, and also the heading control was easy to control. The only deficiency I could see was in the pitch axis on this one. A 3.

[For VCRs:] Attitude control, I would say that it's a 2-1/2. Horizontal translational rate, make that a 3-1/2 due to the fact that it seemed like it wandered in fore and aft. Vertical translational rate, make that a 2.

Run 411 (Vertical Translation). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. The deficiencies did warrant improvement. I would say that it is moderately objectionable deficiencies. Adequate performance required considerable pilot compensation in the fore and aft longitudinal axis. I would rate that a 5. It seemed like the roll was very stable. The vertical axis was also very stable. In fore and aft. it was difficult to maintain a precise position in relationship to the cone. It had a tendency to build up a rate going fore and aft. That's the reason it graded down to a 5.

[For VCRs,] Attitude, make that a 3, fair. Horizontal translational rate, make that a 3-1/2. This is due to the fact of it translating longitudinally, and not being able to hold it precisely. Vertical translational rate, make that a 2. That held in there very good. It was very easy to control.

Run 412 (Slalom). Controllable? Yes. Adequate performance with tolerable pilot workload? Yes. It felt like it was. Satisfactory without improvement? No. I would give it some minor but annoying deficiencies. Desired performance requires moderate pilot compensation. The big thing here, again, was airspeed control, and I think that was directly related to the pitch axis and the longitudinal control. It was difficult to hold on to that 35 knots as we maneuvered down the course. It was very responsive in roll which was good. You could maintain your position within the three

squares of the pillars. A 5.... Minor but annoying deficiencies, moderate compensation, airspeed control difficult to hold at 35 knots — make that a 4.

[For VCRs,] attitude control was a 3-1/2 due to the longitudinal control. Horizontal translational rate, 2-1/2. It was good, we were able to maintain within the three squares, and I felt like I could maintain it fairly precisely. Vertical translational rate, a 2. It held right where you needed to have it as far as the 20 feet, and within the parameters of that.

Configuration E (Fixed Base)

Run 413 (Hover). Was it controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. I'd give it minor but annoying deficiencies. I believe that desired performance was attained for most of the time. In any event there were some excursions, give it a 4-1/2. Noticed on that, once you were stabilized it held pretty much right on the money. When you started to put in small inputs that's when you really started to drift away from the point. You have a tendency to influence the adequate performance requiring a lot of pilot compensation. Again, vertical axis was fairly easy to control. It was just mostly in pitch and roll axes that it was difficult to maintain the desired position. It seemed like there was a delay in the roll axis, but the pitch axis was almost immediate to any control inputs. Rates were established on those almost immediately so that the control harmony was a little bit off there. You had to use one method of control for longitudinal, and one method for lateral.

[For VCRs,] attitude control would be a 3-1/2 due to this control input. Horizontal translational rate — you were able to maintain limited corrections with confidence, and precision was fair to good. A 2-1/2 on that. Vertical translational rate, again that was a 2, that was very well maintained.

Run 414 (Vertical Translation). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I would give it moderately objectionable to very objectionable but tolerable deficiencies. About a 5-1/2. Again, it seemed like the pitch and roll were difficult to control, and to keep in harmony together. It seems like there's a delay in the roll axis, and not in the pitch axis. This causes a lot of wallowing around the attitude of the helicopter, around the roll axis, and not much around the pitch axis until you start to make a control input. It's easy to start a drifting rate, longitudinally where you drift fore and aft. to a great degree due to the pitch-axis control. Again vertical was easily maintained.

[For VCRs,] attitude, make it a 4. Vertical translational rate a 2-1/2. The reason I lowered the vertical rate, I noticed there was a tendency to start some bobbling out there when we were making corrections down low to the ground.

Run 415 (Slalom). Controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. I felt there were some very objectionable but tolerable deficiencies, that adequate performance required extensive pilot compensation. HQR 6. The big thing I noticed was trying to maintain the track going along the ground. It seemed to wander, again, without being able to establish a correction to get the path back where you wanted it. There was a tendency to drift in towards the pylons. Airspeed control was difficult, and this can be the result of the pitch axis and roll axis not being in harmony with each other. Directional control was easy to maintain again in this particular configuration.

VCRs: Attitude, a 3-1/2, on the low side of fair. Horizontal translational rate, a 4. The roll, the sort of a wallowing that we're getting, is conducive to PIO. Vertical translational rate, 2-1/2 on that.

Configuration G (Fixed Base)

Run 416 (Hover). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? No. Deficiencies require improvement. I would give this a 7-1/2. Adequate performance didn't really feel like it was fully attainable, and there was some question with some of the roll attitudes whether or not we were staying in control, so it would be a 7 to 7-1/2. It seemed to be much faster in pitch response then in roll response. This was confusing, it really added to the PIO tendency on this maneuver. Vertical axis, I was able to maintain fairly good control.

[For VCRs,] Attitude control was poor, that's a 5. Horizontal translational rate, make it a 3-1/2 on that. Vertical translational rate, a 3 on that. Again, attitude control, you just didn't feel very confident where you were putting the helicopter. Horizontal translational rates as a result suffered, and you were able to build up high translational rates in both X and Y directions. Vertical-translational rate, again it was controllable.

Runs 417 and 418 (Vertical Translation). Controllable? Yes. Adequate performance attainable? No. There were major deficiencies. I didn't feel like we could really maintain a precise hover with maximum tolerable pilot compensation, however controllability wasn't in question so I give it a 7. It really seemed like it wanted to oscillate or wallow around the trim point, and that's what made it difficult to control. The pitch response does seem to be sharper to the cyclic input than what the roll does, but yet, there is a delay there that causes a PIO tendency.

[For VCRs,] attitude control, a poor — 5 on that. Horizontal translational rate, a 3, fair. Vertical translational rate, a 2-1/2 on that. Again, the attitude control was very poor because of this wallowing effect that we were getting of the helicopter around the lateral and longitudinal axes.

Run 419 (Slalom). Controllable? Yes. Adequate performance attained with tolerable pilot workload? No. Major deficiencies do require improvement. Adequate performance not attainable with maximum tolerable pilot compensation. That's a HQR 7. It seemed like it wanted to wallow in the lateral axis which caused us to come in close to the pylons, and not being able to maintain a precise track across the ground. Airspeed was a little bit more controllable. Not much from the previous configuration. This might be due to the pitch response that we're getting that we're able to maintain in order to achieve an attitude which will give us a reduction in airspeed that we need. Vertically that last time I noticed it did have a tendency to fluctuate, to go low there about midway through the course. I don't know if that was a combination of the lateral and longitudinal in the vertical axis or if it was just a vertical alone. I think it was probably the combination of all three.

[For VCRs,] attitude control for the slalom run I would give it a 3-1/2. It did seem like it wanted to maintain the attitude or it was easy to maintain the attitude, but when you went to make a correction that's when everything went bad. So the horizontal translational rate give that a 5. In vertical give that a 3-1/2.

Configuration J (Fixed Base)

Run 420 (Hover). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Very objectionable but tolerable deficiencies. Adequate performance required extensive pilot compensation. Again, it seemed like it wanted to wallow around the trim point, and this time it seemed like there was a delay in the pitch response, which was greater than the delay in the roll response. There was also a delay in the collective input which added to the difficulty of the hovering task of maintaining a 20-foot altitude on it. That's the reason it's an HQR 6.

[For VCRs,] attitude, I would give it a 3, a fair. Horizontal translational rate, make that a 4 on this. Vertical, make that a 4. Attitude control was only really marginally fair; like I said, there was a tendency to wallow around. Translational rate as a result suffered from this, and then the vertical translation was difficult to anticipate.

Run 421 (Vertical Translation). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes, I believe it was. Was it satisfactory with out improvement? No. There's very objectionable tolerable deficiencies. Adequate performance requires extensive pilot compensation. That would be an HQR of 6. It seemed like it really wanted to wallow around, and added to that was the difficulty in controlling the vertical axis which all compounded itself in not being able to hold the position over the ground, and it wanting to just wander around the hover point.

[For VCRs,] attitude 4-1/2, almost poor. Horizontal translational rate a 4-1/2, vertical 4-1/2, for the reasons that we gave before.

Run 422 (Slalom). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Some very objectionable but tolerable deficiencies. It felt like adequate performance was attained, but it did require extensive pilot compensation. Once we got going moving at a forward rate it didn't require all that much in order to maintain the airspeed. I did notice that when we went to make a slight change to the vertical axis it took a long time for it to take effect through the collective. That could be improved. Again, the wallowing that we got as we went around the pylon, it really wasn't that noticeable on the pylon task. It's probably due to the fact that we have a forward velocity going. I would stick with a 6 on that.

[For VCRs,] attitude control, I did notice that as we went around the pylons it had a tendency to overcontrol slightly so I'd give it a 4 there. On the horizontal translational rate, make that a 2-1/2. It was fairly easy to maintain the track that we needed. Vertical translational rate, make that a 4, just due to the difficulty in the time delays in the collective.

Low-Bandwidth Configuration (Fixed Base)

Run 430 (Hover). Was it controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. Moderately objectionable deficiencies, adequate performance required considerable pilot compensation. HQR 5. I noticed that it had a tendency to oscillate in pitch especially when you were trying to do a very precise hover task. There was a tendency to get into a PIO. This made it difficult to keep the cone in the lower half of the window, and I felt like I was able to keep the cone within the window at least 50% of the time. I was able to maintain altitude very close, plus or minus two feet. I'd say we achieved the desired performance on altitude,

and desired performance on heading. The only thing that was questionable on this was keeping the cone in the window. I noticed that there was a delay in the collective, and its reaction to any kind of input. It took a little bit of time to get it to respond, and it seemed like there was a slight delay depending upon the task that you were doing in either pitch or roll. The precise hover you could see the deficiency in the pitch attitude more than you could in the roll for some reason. I'd have to put a command in to it, and then wait a little bit to get some kind of response out of it. This has a tendency to give it a PIO tendency for a large input movement. Of course in this particular task there wasn't that big a requirement for large-collective inputs. Where I noticed the most control movement was in pitch, and what appears to be a delay.

Run 431 (Vertical Translation). HQR's: Was it controllable? Was adequate performance attainable? I think it was. Was it satisfactory without improvement? No. I'd say there's some very objectionable but tolerable deficiencies, and adequate performance requires extensive pilot compensation, HQR 6. Again, what I was noticing was that natural movement to the point and away from the point was fairly easy controlled once the rate was established. It was trying to get this movement along the ground established that was difficult. You didn't know how much attitude change you really needed to get a translational rate going. Consequently you put in a little bit, you'd see the nose bob, or the wings dip, and nothing would happen so you'd think it needs a little bit more. You were fighting this tendency, and consequently putting in too much, and having to take some out or go the opposite direction which caused you to be very jerky. When you got down low to the ground in the pitch axis, longitudinally going fore and aft then as you moved away it became very evident in the roll axis in trying to establish a factor away from the cone.

Runs 432 and 433 (Slalom). Okay, I thought that was pretty easy. It seemed like everything sort of stayed in there, and I think desired performance was achieved. With that in mind, I would say: Yes, controllable. Adequate performance attainable? Yes. Satisfactory without improvement? Yes. I give it a fair, some mildly unpleasant deficiencies, there were some excursions of altitude low, but nothing out of the limits. I'll give it an HQR 3 because minimal pilot compensation was required for desired performance. It seemed like it was fairly stable going around the poles. Like I said the altitude did get down, I think I saw it 10 feet at one time. It was fairly easy to maintain within three squares, without hitting a pole, and it seemed very responsive to pitch and roll. They could be anticipated adequately enough so not to overcontrol, and be able to maintain a precise track along the ground.

Low-Bandwidth Configuration (Fixed Base)

Run 434 (Hover). Was it controllable? Yes. Adequate performance attainable with a tolerable-pilot work load? Yes. Satisfactory without improvement? No. I'd say that there were moderately objectionable to very objectional deficiencies, and give it an HQR 5-1/2. The main thing I noticed was that when you went to put an input in, it took a while for the aircraft to react to the input. You'd get a roll, the visual sighting of the roll, but nothing would happen as far as your translational path across the ground. Just about the time you did get a translational input you'd better be thinking about taking it out because you're going to go too far. I thought that is a result of attitude tendency for overcontrolling. One technique that I tried using on this was very short inputs with cyclic to help to maintain over a spot. That really didn't seem to help. I could still see the deviations for about the first 30, 40, 45 seconds of the maneuver. It was fairly easy to keep the cone in sight, but for some reason during the last 15 to 20 seconds of it, it just seemed to become almost impossible to keep it in that lower portion of the glareshield. Collective — altitude control is very easy on it. It seemed like at one stage to drive around the place and height that we wanted.

Run 435 (Pirouette). It was controllable. Adequate performance was attainable. Satisfactory without improvement? Yes. I'd say that it's probably good to fair, and give it a 2-1/2. There's some minor to unpleasant deficiencies in it. It seemed like it got fairly well established going around the circle with very little input necessary. If you did go to make a change to it, that made it more difficult. It really didn't seem like it needed that much correction going around. It maintained altitude all the way around, and I was able to maintain the speed after we got going to the side. Both directions seemed equally as easy to maneuver around the circle. I couldn't see anything that was super wrong with it.

[Note: Runs 440-456 had incorrect motion system and were deleted from analysis.]

Baseline Configuration

Run 462 (Hover). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I would say that there's minor but annoying deficiencies. Desired performance requires moderate pilot compensation. The big thing that I noticed here is that it seemed like you can get a handle on the longitudinal translational movement, and maintain it with just slight changes in pitch which produced a very responsive translational rate. It seemed like lateral had a tendency to drift off, and it was difficult to bring it back. The motion seemed to be in phase with the longitudinal fore and aft. The lateral did too, but it just seemed like it took more time for it to take effect in lateral than for what it did in the longitudinal so that would be an HQR 4. Vertical control is easy to maintain for this.

VCR's: Attitude, I would give it a 3-1/2. Horizontal-translational rate, I give that a 3-1/2. Vertical, I give that a 2.

Run 463 (Vertical Translation). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. This one I would make as minor to moderately objectionable deficiencies so that's an HQR 4.5. Laterally, it seemed to be more exaggerated in this as you moved in and out. It did seem fairly easy to control. It's fairly easy to see movements right away in keeping the cone down in the lower portion of the windshield. Vertical was fairly easy to control so that would make it an HQR 4-1/2.

[For VCRs,] attitude control — in general, make it a VCR 3. Horizontal translational rate — make it a VCR 4. Vertical translational rate — make that a VCR 2-1/2.

Motion — it doesn't seem like there's the same rate in roll rate that we're getting with pitch rate in the thing. It seems like the roll rate is much slower than the pitch rate. The actual pitch response is quicker. The roll response seems to be somewhat delayed so you're getting excursions away from the exact point that you want to be at. Again, you're back to the point of not being able to determine when to put it in or take it out to get the kind of translational rate that you want.

Run 465 (Pirouette). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. I would say that it was fair, some mildly unpleasant deficiencies. I give it a 3. Minimal compensation is required to achieve desired performance. The lateral translational rate could be easily achieved and precisely controlled as we went around the circle, and it looked like it could also be controlled in fore and aft in the longitudinal direction with just very little input correction to it. Height was easily controlled with the collective. It didn't seem to be a problem in either way. Going to stop it, it came to a precise stop,

and was easily controlled as we stopped it. The rate seemed good going all the way around in performing the task. Nothing seemed like it was getting overcontrolled, or there was a tendency to PIO. The only thing I noticed a slight tendency to PIO was at the end when you were trying to come to an abrupt stop, there was a slight tendency to excite the longitudinal, to start some excursions going longitudinally. That might lead to a question whether you'd really want to stop that abrupt in a real machine.

VCRs: Attitude control, I'd say, would be a 3-1/2. This is mainly just due to a slight overcontrol that we were getting. Horizontal translational rate, make that a 2-1/2. That was fairly well controllable. Vertical translational rate, that could be a 2.

<u>Runs 466 and 467 (Slalom).</u> Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpleasant deficiencies. Minimal pilot compensation required. I give that a 3. The main thing I noticed on this, as we went around, it seemed like the helicopter sort of skidded out as we ran around the turn. It didn't seem like it was smooth going around, and we sort of slid out to the side, on each side of the pylon. It didn't seem realistic with this kind of slide even with a little bit of pedal input to keep you coordinated. It was almost like the rotation wasn't correct for a turn like that, a short turn and a tight turn, in this particular maneuver, so I'd say you'd have to compensate for that. Vertical control is easily maintained, very responsive to it, and it seemed like the motion was adequate for it, so that would still just give it a 3.

VCRs: Attitude control, probably because of the slight tendency to skid out on it, give it a 3-1/2. Horizontal translational rate, a 3. It seemed like it was fairly easy to control as we went along the ground, and fairly easy to maintain a desired path in spite of the slight washout. Vertical translational rate, make that a 2-1/2.

<u>Run 468 (Bobup/Down).</u> Is it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. There's mildly unpleasant deficiencies. Minimal pilot compensation required. Make that a 3. The big thing I noticed here was that there was a slight tendency to overshoot, but it seemed to dampen out very readily and positively with just a few collective inputs. The collective inputs or the rapid movements of the collective did have a tendency to excite longitudinal/lateral. Once you got down within some kind of ground reference, it was very easy to dampen out these oscillations and keep within the parameters of the 3 squares of where you were supposed to be. You did lose sight of the visual very quickly after pulling in the collective, at least the visual scene underneath it, so this had a tendency to cause you to drift a little bit in longitudinal/lateral orientation. There was also a tendency to overshoot as you came back down with rapid movement of the collective. This could be dampened out fairly well with the collective, and without any undue effort on the pilot's part.

VCR's for this: Attitude, make it a 3-1/2. Fair. Just due to the situation that you get in the lack of the references that you have for the attitude, both in lateral and longitudinal. Horizontal translational rate would be a 2-1/2. It didn't seem like we drifted all that much, but it wasn't really correctable. Vertical translational rate would be a 2. That was very well controlled, and without being able to overshoot.

<u>Run 469 (Dash/Quickstop).</u> Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpleasant deficiencies, to a good, negligible deficiency. Make that a 2-1/2. It seemed like it was

fairly easy to get the thing going. Very controllable on attitude. There's no tendency to overshoot. It felt positive response during the whole pitchdown motion, and nothing that seemed out of control. It accelerated on out to 60 knots, and it was very easy to control the attitude and the vertical component with just the pitch control. During the deceleration it looked like it had a tendency to turn a little bit, but that could easily be controlled with the collective and pitch control. Motion cues felt good in it throughout. It was like you were actually pitching forward, and then doing the deceleration at the far end as if you were really decelerating. There were no disorienting motion or visual cues through it, and it all seemed fairly reasonable.

VCRs: Attitude control throughout would be a 2-1/2. Horizontal translational rate a 2-1/2. Vertical a 2-1/2.... Make attitude a 2, horizontal translational rate a 2-1/2. This was a little bit lower, because at the end it was slightly difficult to judge a deceleration rate. I slowed down a little bit early, and I wasn't able to bring it to as precise an end as what I would have liked. Vertical control, we did have a tendency to drift down there towards the end as we went to decelerate. We dipped down, and then ballooned at the end.

Run 470 (Sidestep). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. There were moderately to minor deficiencies in this. The desired performance required moderate to considerable pilot performance. Make it a 4-1/2. The main thing I noticed on this was during the initial lateral acceleration, the hovering task, and then the deceleration, it had a tendency to wander around the hover point. When you went to bring it to a stop after accelerating laterally, it was difficult to maintain a precise hover point at the end. It had a tendency to drift off, and there was a tendency to overcompensate for it. Altitude control was fairly easy to do. Initial roll rate, I was getting greater than 20 degrees of bank, and it was easy to achieve and maintain throughout. It didn't seem like it was showing you any kind of unusual attitude or out-of-control condition. The only thing that really felt uncomfortable was the decelerations at the end. There was a lot of wallowing around the hover point in trying to maintain a spot right over the ground.

VCRs: As far as attitude control, because of the end points I would give it a 4. Horizontal translational rate, a 3. Lateral rate was easier to maintain than the fore and aft one. I noticed that it had a tendency to drift a little bit fore and aft due to the visual cueing out here. It was difficult to notice which way you were going until you saw the red and green line moving. Vertical translational rate, make that a 2-1/2. It was slightly difficult to control during the initial 20 degree bank, but fairly easy the rest of the time.

Pilot comment card: Is your flying technique modified because you're flying a simulator? Yes. The main reason is that you can be more aggressive than what you would be in a normal aircraft because you know you won't crash. You won't snag a rotor blade or something. You have a tendency to be as aggressive as you want without the fear of dying. Comment on aircraft response: It seems the aircraft response is very crisp compared to normal helicopters that we fly. Any unusual characteristics? The inertia feel, again, it does not feel like it's in the simulator as what you have in the actual helicopter. What seems to be the biggest defect of the simulators is that you just don't have that mass that you're moving around like you do in the actual machine. How did the motion cues affect your control of the rotorcraft? Valuable for control? Yes. It helped you determine what kind of rate you were going achieve as far as longitudinal, lateral, and vertical rates, so of some value, but not very realistic. We haven't flown any other motion systems other than this one. Motion/visual cues? In this, they seem to be fairly consistent. Is there any unusual, conflicting or uncomfortable visual/motion cue? The only thing that I noticed, it seems like in the lateral axis the roll that you get

resembles the real helicopter better than what the pitch axis does. It seems like there's sharper acceleration. Today, for some reason, versus the other day it doesn't seem to be as predominant now. I don't know, maybe it's just me, or something has been changed, but it does feel a little less sharp in the pitch axis which is good because it's what you would expect in the real machine. Any feeling of nausea or discomfort? Just the first time I flew this system, there was a slight bit of discomfort. There was nothing that you couldn't fly through. Today, I didn't notice anything. Obvious deficiencies in the visual scene? Outside of not being able to get any kind of texture from the ground, and it sort of being unclear as to where the surface is, I don't see any other deficiencies. Unfortunately, for these kinds of tasks, you've required a very high-gain, high-performance type task with a very low-gain, low-performance visual system. It's almost unfair. I think if your visual scene was better, you'd see better performance in the actual performance of the task, but that's a comment that's been common with this visual system since I've flown it.

Low-Bandwidth Rate

Run 471 (Hover). Was it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I would say that deficiencies warrant improvement. They are very objectionable but tolerable, and adequate performance requires extensive pilot compensation. I'll give that one a 6. It's between a 6 and a 7, but I have a feeling that the pilot could learn to live with this control configuration. The thing that I noticed, it seems like the motion system was constantly in motion after it appeared visually that the scene in the helicopter was stable, and this was a little disconcerting because you didn't know how to steady this thing out. It continued to bobble around the point in both pitch and roll without you putting any input in to it. The control system seems good, as responsive as the ones we've seen before, but it's very much time delay, and the total motion response seems like it's stretched out over a long period of time. It looks like the motion starts fairly quick. You do feel an acceleration, but like I say it does stretch out for a long period of time. This degrades the performance of the hover task. It's like being on a rubber band where you just continue to oscillate, but if you look at the picture in front of you, you're not oscillating at all. It's fairly stable as to where you're at. There's an awful lot of travel to the motion system because you are feeling more of a sinking feeling. You could really feel it in here when it's moving around. There's a longer stroke to the motion system. Like I say, this is what's degrading the performance of it. You're feeling that you want to correct for that, but the visual scene is telling you everything's okay. You really are in a good position. I did notice one time, on that cone over there, that about 30 or 45 seconds through the hover, we really started going all over the place. It didn't appear that the cone was moving all that much or all that fast, but the motion system gave the feeling that we were really being tossed around. It just compounded itself, and made the task more difficult.

Run 472 (Vertical Translation). Controllable? Yes. Adequate performance attained with a tolerable workload? Yes. Satisfactory without improvement? No. Again a 6. Very objectionable with tolerable deficiencies. Adequate performance requires extensive pilot compensation. Again the low damping, and the motion system is causing some PIO in to it in correction. It's very difficult to hover just by orienting yourself to the cone on the side. You really start up a lateral movement and lateral rocking motion with it. I think that's just because you're feeling this motion system coming in so late, or so stretched out, that you're trying to correct for it when you may not need to actually correct for it. Of course there's no way to tell if you're not looking straight ahead. If you look straight ahead, and then you realize that you really don't need to correct for that lateral movement that you're not moving that much, yet the motion system gives you the feeling like you are moving. Like I said, if you're staring out to the side or concentrating out to the side then you have the

tendency to go ahead and correct for the motion that you're feeling, and as a result you just make everything worse, and you do start changing the visual and it's very easy to become disoriented on it. Translating to the side and up to the takeoff portion of it seems to be fairly well controllable. It seems like it responds fairly quickly to a control input. It was somewhat easy to control the altitude upon reaching 30 feet without overshooting it too much. There was a slight tendency to overshoot, but I don't think that would be anything that we couldn't overcome. The real trick was the precision hover down to what would be called the landing point or the ten-foot point. You may have corrected the motion since the motion made me feel good, but the actual visual scene makes me feel bad or it looks bad.

Runs 473 and 474 (Slalom). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Minor but annoying deficiencies. Desired performance requires moderate pilot compensation. That would be an HQR 4. Pretty much within all the parameters. We may have been pushing the 3-square around the pylon there. On the second or the third pylon they were tight pylons. I couldn't see the ground track, but it felt pretty good going through it. I did notice that there's a tendency for it to sort of wash out on the side. You really got the sense in the cockpit here that you were sliding out to the sides, and it continued even though you put a control input in to start a turn back the other way. It still felt that you were in a skid going around the pylons. Vertical was easy to hold. There wasn't any change on it that I could see. It looked like it stayed right at about 40 feet. Power response was good. Actual control response with the visual scene was good. There was just a tendency like I said for it to appear that it's skidding as you went around the turn. Actually you couldn't control it that much with a little bit of tail rudder, because you were actually starting a turn towards the other direction.

Run 475 (Bobup/Down). Was it controllable? Yes. Was adequate performance attained with tolerable pilot workload? Yes. Satisfactory without improvement? No. Make it minor to moderately objectionable deficiencies, a 4-1/2. The reason I'm saying this it seems like the control response is good to the visual scene, and it's fairly easy to get the desired input, and get the desired visual change. The problem that comes in to it is with the motion, and again, it's the lack of damping. I guess the easiest thing to equate it to would be being on a rubber band. It just seems like we sit there and oscillate back and forth. It takes quite a long time for it to steady out. I notice that it seems like there's a lot of movement with the motion system. You can really feel it in your stomach when you dump the collective that you are actually sinking. At the bottom you get definite positive force when you pull back in on the collective to stop this sink rate. It reminded me of having a weight on a rubber band. It's how it bobbles, and doesn't really dampen out. It's oscillating when it's sitting there at the end of the string. Lateral translation on this, again, had a tendency not to dampen out. I noticed that this was even evident in the control system and the visual scene along with the motion. Even when we were steady on the visual and controls, I could still feel the motion system moving around trying to anticipate or go to some sort of position underneath it when we weren't actually moving. That made that particular part of the task more difficult.

[Comment card:] Comment #1, flying technique modified? Same comments as before. You don't have the fear of crashing. Comment #2 on aircraft response? Control system with the visual seemed fairly crisp. The motion system seemed sluggish, and not damped. It's sort of a contradiction there. Comment #3, I would say that the motion cues affected the ability to control the rotorcraft in a negative way. You sort of had to overlook the motion cues, and just look what the attitude of the helicopter was doing visually, and try to correct for those, and throw the motion cues out. The motion system with the other systems flown in this experiment, like I say, seems not to be damped,

and it exhibits itself as being very prolonged. Motion system and visual cues did not seem consistent for the reasons that were stated before. The only conflicting, uncomfortable visual or motion cues would be those where you're trying to perform a precision task — i.e., hover or the bob-up maneuver. The motion felt like it was moving the machine, but the visual was staying constant. A feeling of discomfort? No, I would say that it's a very smooth motion system as opposed to some of the jerky-quick responses that we've had in motion systems. It's also a very prolonged response, and more in the obvious deficiencies of the visual scene except for those noted before, the lack of texture on the ground, and the inability to see small changes.

Low-Bandwidth Rate

Run 476 (Hover). Controllable? Yes. Adequate performance attained with tolerable pilot workload? Yes. Satisfactory without improvement? No, I'd say that there were moderately objectionable deficiencies. Adequate performance required considerable pilot compensation, HQR 5. On this, it felt like the control system was less damped, and there was a tendency to have oscillations around the hover point. It also seemed like the control system was slow to respond to input movements. The motion system in this case seemed to be fairly-well damped, and fairly-well true to what was going on. The only comment I have about the motion, it seemed like it was still working after we achieved a position. Even though I didn't get a feeling of motion, I could still hear it moving underneath me. It seemed like it really wanted to oscillate in pitch and roll. The vertical component was fairly easy to control. It was just mostly pitch and roll with pitch probably being the primary. There was one point there where you had a tendency to drift forward and to the miss cues on the ground. I was slow to react to that, and keep it back in. That's the reason the rating was dropped down on it. Lateral cues? Again, the lateral movements had a tendency to oscillate somewhat when you stared at the target cone down there, and lost sight of the forward visual picture.

Run 477 (Vertical Translation). Is it controllable? Yes. Adequate performance attained with tolerable pilot workload? Yes. Satisfactory without improvement? No. Minor but annoying deficiencies. Desired performance required moderate pilot compensation, HQR 4. The motion system does in this particular movement appear to be more damped than the previous configuration that we've had. It seemed like it dampened out quite rapidly, and there was no tendency to overshoot. It's the control system in this case that seemed like set up oscillations, but makes it more difficult to control. It doesn't appear that you've actually set up translational rates with a lot of your pitch attitude changes and roll attitude changes as opposed to just being moved around the center point. It requires holding them in, for a little bit of time, in order to get the translational rate going. This might have had the effect of moving on to the point before you realized it, especially if your attention is diverted to something else like altitude or whatever. You might have found that you drifted fore/aft. I think that happened when we initially started our climb up to 30 feet. Like I said the motion does appear to be damped, and it felt pretty good in this case.

Run 478 (Slalom). Controllable? Yes. Adequate performance attained with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. I would give this a 3. Fair, some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. This, all in all, felt pretty good. The motion cues were adequate enough, and this time there was none of this sliding-out tendency to the side as we went around the pylons. It felt like we were able to maintain a fairly precise course going through them. I think there's one tendency on about the second pylon where we might have been a little high on airspeed. It was tight getting it around, but it seemed fairly controllable. It did seem like there's a little bit of tendency to overcontrol or that the control system wasn't damped enough to maintain the desired bank attitude that you want when you went

around the pylon. Vertical control was fairly easy to maintain through use of collective, and I think there was only about one point where we got down to about 13 feet. All in all, I'd say that the motion felt pretty good on that.

Run 479 (Bobup/Down). Was it controllable? Yes. Was adequate performance attained with tolerable pilot workload? Yes. Satisfactory without improvement? No. I'd say that there were minor deficiencies to moderately objectionable deficiencies, but desired performance could be attained, and make it a 4-1/2 on that. The main thing I noticed on this, it was difficult on the descent to maintain a level attitude in pitch and roll. It seemed that I wanted to oscillate around a little bit. In the vertical path, going up initially it was very easy to come up to the desired altitude and hover on the target, and it could be done very precisely. For some reason when we went to a descent there's a tendency to oscillate around in pitch and roll. The motion cues seemed pretty good, and on time with it. It's not out of phase or not undamped. They were pretty well damped with wha we were seeing. Visual cues were okay, and just the control movement seemed to be less dampe than the systems before.

[Comment card:] Was control technique, flying technique, modified because you're flying simulator? The same as before. Aircraft response. It seemed to be more crisp this time than wh it did before. Even though there was some slight overshoots on the control movements, moti system gave it a feeling of being much more crisp in response. Motion cues? I would say that th were valuable for control, especially exhibited by this last one where it was pretty easy to maint that one target. The motion cues were valuable for control, but the control system could use so work. It was deficient in this. This motion system seemed to be much more damped, and m realistic than what some of the other ones were before. Did motion and visual cues seem consiste Yes. Were there any unusual conflicting or comfortable visual-motion cues? No. Not this time feeling of discomfort or nausea? I did notice on the initial hover there was some tendenc discomfort, but it had a tendency to go away. I think this just could be the control delays tha were seeing in the control system during the hover task. It was causing the visual scene to be m around a little bit, and the deficiencies in the visual scene remained the same as before, meaning of definition, lack of detail in the surface. Just poor visual scene without being able to see pr definition on the ground at all. It really becomes difficult doing tasks like the hover task. example, it's difficult to judge depth perception and rate of closure without more detail on the s

Configuration N

Run 480 (Hover). Was it controllable? Yes. Adequate performance attainable with tol pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpl deficiencies. Minimal pilot compensation required for desired performance. HQR 3. I i thought when I had this combination that it was going to be more difficult to maintain the It seems like the control inputs are damped enough, that even though they're delayed in taking the damping on them is fairly easy to take out so you can maintain a fairly stable hover. Th a slight tendency to drift around, but this was easily controllable with just a little bit movement. Vertical motion was easily maintained with the collective, and I didn't find anythi wrong with it. Motion cues seemed to be okay for this. It mainly seemed like a delay in the taking effect was giving you a translation along the ground, but it was fairly well damped that's the reason for a high rating like a 3.

Run 481 (Vertical Translation). Controllable? Yes. Adequate performance attain tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies

improvement. Minor but annoying deficiency. Desired performance requires moderate pilot compensation. This I noticed, that it was a little bit more difficult to get aligned with the cone out there, and the lower portion of the window, and then to maintain this alignment as you did the landing task down to 10 feet. It didn't want to drift out of the area on the window or it had a tendency to drift but you were able to maintain it in the lower portion of the window, and at the desired height. Translation was easily controlled as you went out to the 30 foot height, and then back down to the 20. It just seemed like the helicopter was bobbling around more than what it had on some of the other configurations. Again this could be due to being closed in on the loop with these control inputs, and not able to anticipate to an adequate extent the amount of control movement that's necessary. Again, the rates that were developed are easily controlled, and control inputs were well damped so there wasn't any question of being able to maintain desired control or performance. Vertical, again, was easily controlled, and without any overshoots on it, and motion seemed to be okay on this so I would give it an HQR 4.

Run 482 (Slalom). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair with some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. An HQR 3. This seemed very controllable, very responsive to power inputs to get the altitude back up where we needed it, and the airspeed at 40 knots. It seemed to have positive control going around the pylon, and didn't want to wash out like some of the previous configurations or just skid around the corner. There is a slight unsteadiness to it at times, but that's just with a high banking commanded. Due to the probable lateness with the control, it had a tendency to sort of oscillate at that high bank angle, I was sorry I couldn't command a definite figurative bank. We stayed within the three squares as we went around the pylons without any difficulty, and it really didn't seem like the first two or three pylons that were close together were any problem either. In general, it felt pretty good. The motion felt pretty good too on it, in sync with what we were doing.

Run 483 (Bobup/Down). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Minor to moderately objectionable deficiencies, make it a 4-1/2 on this. It was a little bit difficult to control the vertical axis. There's a tendency to overshoot, primarily on the descent, coming back down to the bottom. I don't know why that would be. Maybe the acceleration is faster coming down than what we had going up. It seemed to be fairly stable longitudinally and laterally, in pitch and roll going up around the hover boards. It was just a question of trying to maintain the height when we came down. Like I say, there's a slight overshoot on it. It seemed fairly well damped out, but you're not sure about how much to put in to damp this out. I think with a little bit of learning the pilot could probably achieve desired performance. I give that a 4-1/2.

[Comment card:] Comment #1, flying technique modified? The same comments as before. Comment on aircraft response? It seemed a little bit sluggish, but it was well damped so that you could anticipate its sluggishness. Motion cues were of some value for control. They did seem fairly realistic. This motion system did seem to be fairly realistic to the control system. Motion/visual cues? Did seem consistent. Any unusual, conflicting or uncomfortable visual/motion cues? No. No feeling of discomfort. Obvious deficiencies in the visual scene? They remain the same as before. There's the lack of texture, and lack of being able to determine your height. This could have been a big thing in both the hover task for landing, and the bobup/bobdown in that you were unable to determine where the ground was, and put the corresponding input in to it. That also had a tendency to affect Common 1, flying technique, in that in the simulator you could make much more aggressive moves with the controls. On the bobdown part of the maneuver, you're not afraid to dump the collective

because you know you won't crash in to the ground. In a real machine you might be a little reluctant just to dump the collective, and know that you could pull it in at the end or hope you could pull it in the end, arrest the descent rate.

Configuration D

Run 484 (Hover). Is it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Minor to moderately objectionable deficiencies. Desired performance required moderate pilot compensation. Adequate performance required considerable, give it a 4-1/2. I noticed on this that the full input seemed to respond visually very quickly. Visual presentation, motion presentation as far as pitch and roll go, and vertical. What seemed to be delayed quite a bit was the actual effect of the control displacement both vertically, laterally, and longitudinally. As a result, it gave you a feeling that you were overcontrolling a lot of the time, and that you were putting in excessive control inputs to maintain the hover. I found it was quite a bit of movement of the stick in both longitudinal and lateral axes to try to maintain the hover point out there. This would be the reason to degrade it. It did seem like you could maintain the cone in the window, and the particular target area you wanted to, but there was an awful lot of work in doing it, an awful lot of movement of the cyclic control. Motion seemed like it came in later on. It seemed like there was a sudden acceleration of motion, and then it seemed like there was a continual sort of wash out of the motion as the control input was taking place. There was like a slight jerk, and then a smoothness of the motion that you were still moving as you began your translational rates out there.

Run 485 (Vertical Translation). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Make this moderately objectionable deficiencies. Adequate performance required considerable pilot compensation. Really noticed on this as we got down close to the ground, close to the cone, that we had a tendency to wallow around in both pitch and roll. It was difficult to control, I think we did stay within the parameters for adequate, but it was still difficult to control it in a stable attitude. You almost had to accept a lot of the wallowing to do the task. As we climbed up in altitude, you continued to wallow, and sort of stabled up somewhat in the 30 foot altitude, but not where I would put it down at desired or any of those categories so I would say that it would be a definite 5. Motion cues seemed to be okay even though they seemed to be fighting what you were experiencing visually. The control input that you were putting in seemed like it was coming in late on it, but as far as magnitude and that sort of thing, we seemed to be okay.

Run 486 (Slalom). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpleasant deficiencies. Minimum pilot compensation required for desired performance. HQR 3. This is just a lot of the same, and then it seemed to wallow around the corner a little bit, but it was nothing that was uncontrollable. It seemed like you can anticipate what kind of control movements that you needed so that you couldn't overcontrol. You had to be aware that they didn't appear to be damped or as damped as before, and that you needed to take the control inputs back out. The altitude did drop a little bit, but nothing excessive, and the airspeed climbed up a little bit, but again, nothing excessive. Overall, it seemed fairly good. Motion seemed, just the same comment as before, that it was in sync with the effective control movement. Not so much as the exact control movement itself or the timing of the control movement.

Run 487 (Bobup/Down). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Adequate performance attainable with tolerable pilot workload? No. Deficiencies require improvement. Major deficiencies. Adequate performance not attainable with maximum tolerable pilot compensation. Make that a 7. The main reason I'm saying that is that it was very difficult to maintain a precise hover height where you can actually use this maneuver for a sighting or something like that. At least at low altitude, and it seemed like it was manifesting itself from the higher altitude. I think there would be an awful lot of work going on with the thing at the low altitude. With a little better stability at the bottom, it could be upgraded to a 6, but you've got to make a choice between the two there. There did seem to be a lot of PIO at the bottom due to the control system, and a lot of overcontrolling. There's one time there where it did excite the lateral and longitudinal and made a hover kind of difficult. For some reason the top hover seemed to be a little more stable, but yet hitting that precise 50 foot altitude was difficult so that's the reason for the lower rate. Motion system same comments as before. It seemed to lag the actual control input, but yet it seemed to be a favorable control response.

Let's go though the pilot comment card. Question #1, same comments as before. More aggressive in this than what you would think in the actual helicopter. Aircraft response, in this seemed a little more sluggish, unable to do things precisely with this configuration. Motion cues of some value, even though they appear to be late, this motion system compared with some of the others, where we have made comments on that already, about it appearing to be late. Motion/visual cues did seem to be consistent. There were no unusual, conflicting, or uncomfortable visual cues. No feeling of discomfort, and obvious deficiencies of the visual scene. Just the same comments as before.

High-Delay Configuration (383 msec)

Run 488 (Hover). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? No. I would say that this is verging on a major deficiency, and considerable pilot compensation is required for control. Make it an 8. It seemed like there's no damping to this at all. You're really fighting it in the lateral axis in this particular maneuver. It seemed fairly stable there at the beginning, but towards about three quarters of the way, it really started to wobble in roll, and it became a very difficult task to even keep the cones in the window, hardly in the lower portion of the window. I would give it an 8 on that. The motion just added to the problems. It seemed to be in sync with the control movement, and not too excessive just to get impression to the control movement. They were all excessive, but there was nothing you could really do to them to dampen them out or reduce the intensity of them. I guess that would mean that there would be a slight delay in the control response, and that the control response would be much greater than what was commanded by the cyclic control.

Run 489 (Vertical Translation). Controllable? Yes. Adequate performance attained with tolerable pilot workload? No. Deficiencies warrant improvement. Major deficiencies. Adequate performance requires extensive pilot compensation, a 6. It did seem like once you got away from the cone, somewhat stable, and of course once you're up and away, controllability never became a question. There might be some question in actually doing the landing task which is difficult to do here in the simulator because you can't get down that close to the ground environment. That might lower the rating if you got down that close, and make it almost an 8. If you're talking about strictly the cone task of trying to land it the 10 foot height, it would be an HQR 8, but considerable pilot compensation was required. But up and a way, a 6, which I know it makes it difficult for you guys

out there. It seemed like during the precise hover task, down low, there was difficulty in maintaining the attitude that you needed for the landing. Maintaining attitude as you did the takeoff, it seemed fairly stable once a rate was established. You didn't have to vary anything too much. Coming to the high hover at 30 feet, again, you ran in to the problem of precise hovering, but at that altitude you didn't need to be quite as precise in maintaining your controls as far as your attitude and height go. Again, it appeared to be control damping that was the big problem, and the magnitude of the control input that you would get with just a slight movement of the cyclic.

Run 490 (Slalom). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Minor to moderately objectionable, make it a 4-1/2 on this, in that you're requiring moderate considerable pilot compensation. This really felt like it wallowed around the pylons, and it was difficult to maintain a precise bank. The helicopter responded quickly to an input so it wasn't a problem there. Had there been delays in it you might lower or degrade the HQR even more, but it did respond quickly, and made a correction, and due to the rapidity as far as the pylons coming up, I think this was the reason you didn't see the lack of damping except for the oscillation in roll as you went around the pylons. Motion seems to be responding to the characteristic control response that you were getting out of the system, so there wasn't a problem there. In collective it seemed to respond okay as far as height goes.

Run 491 (Bobup/Down). Controllable? Yes. Adequate performance attainable with tolerable pilot workload? No. Major deficiencies. Intense pilot compensation required to retain control. This just had problems all through it. It seemed like there were definitely control delays in it that you just can't overcome in using normal control technique or even any kind of abnormal control technique that I could see. There was a definite delay in the collective, what appeared to be like about a half a second from the time that you pulled it in to the time that you got any kind of response feeling in the motion system, or even seeing it in the visual. It seemed like everything was excited around the two hover points that you had, and plus the fact that you had very little damping in it so you were just constantly fighting the system the whole time. I think the question whether you can really retain controllability might even come about in this case, but it's a definite 9 on this.

[Comment card:] Same comments on number one. The aggressiveness? You could be a lot more aggressive on this, the simulator, than the real airplane. Comment on aircraft response? Very sluggish. A lot of overshoots. It just doesn't seem like it responds to the control inputs that you put into it. Motion cues affect your control of the rotorcraft? They were valuable. They were late along with control response so it gave you a feeling that everything was happening late, and added to the PIO tendency. This motion system compared to the others? It seemed like they were fairly much in phase with the control response that we put in, not so much the control input. Visual and motion cues? They seem to be fairly consistent. There were no unusual, conflicting, or uncomfortable visual or motion cues. Oh, yes, probably the only conflicting one would be in the lateral. It did seem like we got out of phase with lateral inputs or lateral visual cues to lateral motion cues in that we were going one way, in one direction. That might have been true on pitch also, but I didn't notice it that much. There was a feeling of discomfort and disorientation during the task, especially the bobup/bobdown, you just didn't know where you were going, and it was a matter of hanging on for the ride most of the time, and trying to freeze the controls to get the inputs to dampen themselves out. Any obvious deficiencies in the visual scene? Just those before. We don't have any texture of the ground, and the depth perception is thrown off.

ACAH

Run 493 (Hover). Was it controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Good to fair, negligible deficiencies. Pilot compensation not a factor for desired performance with minimal compensation required, I give it a 2-1/2. I noticed that it was very stable around the point once you got established. However, getting established on the point was sometimes difficult, and it had a tendency to drift around that. Making small corrections for it as it was drifting away was hard to judge, and as a result made it constantly a little difficult to maintain the position, but not bad. In the vertical axis it was okay. Motion system, when you did put an input in you seemed to rotate around your CG and then start a movement forward which had a tendency to be a little disconcerting at times. It seemed like there was almost too much rotation around the CG — sort of like in a swing or rocking. It would rock, and then all of a sudden it would kick in and move forward with you. On real small inputs this was more pronounced, so I'd still stay with a 2-1/2 on that.

Run 494 (Vertical Translation). Controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. Minor but annoying deficiencies. Desired performance requires moderate pilot compensation. What I noticed on this is that it seemed to be almost too stable around a particular point, and it was difficult to get a translational rate going to follow a particular line up and down away from the hover point either at the 10-foot level or up to the 30-foot level. It was very stable, but like I said it was difficult to get a rate established translationally along the ground. Again, same comments on the motion as before.

Run 495 (Pirouette). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpleasant deficiencies, minimal pilot compensation required for desired performance. It seems like a very stable platform that you're trying to steer around the pirouette circle. It responds good to all the control inputs that you put into it. Once you establish a rate it seems to maintain it, and stays fairly stable, in altitude and ground path as you go around the thing. Motion seemed to follow control inputs and visual scene on this one. I give it a 3.

Run 496 (Slalom). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. Fair, some mildly unpleasant deficiencies, minimal pilot compensation required for desired performance, an HQR 3. This seemed fairly good. The only thing that would degrade it would be what felt like a little lack of controls as we went around the pylons. It felt like they are dishing out on either side, and it did seem like we were following a definite ground-track. Everything on this compared to the other systems that we have, especially on this one, everything seemed slower. It seems easier to control the speed and the altitude on all these configurations that are translating like this. It became very stable, it didn't want to drift at all away from the 40-knots. I think it did get a little slow, but on the other systems it seemed like it wanted to go fast as you went around those pylons. What may have degraded how it would be, the motion system, as we went around the pylons. It almost felt like they were going the wrong way, like we were getting some adverse forces in there, but it may have been because the turn was not coordinated or something like that. I would stick with that HQR 3 on it.

Run 497 (Bobup/Down). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. There's some mildly unpleasant deficiencies. Minimal pilot compensation required. HQR 3. It just seemed to be a little bit of overshooting on the bottom end. Top was positive, you could achieve the 50-foot hover on

the hover boards fairly quickly in a good stable manner. It seemed like you run out of inertia on that as you go up. It's fairly easy to arrest your rate by just reducing the collective, and it reduces the rate very rapidly. On going down, it's a little more difficult to arrest your rate. As you come down there's a tendency to overshoot around that point, and also a slight tendency to excite the longitudinal and lateral axes on it. Motion system, no negative comments on that. It seemed like it followed fairly well to the control-system movement of the helicopter.

Run 498 (Dash/Quickstop). Controllable? Yes. Was adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. I'd say this is probably minor to annoying deficiencies, but annoying deficiencies. Moderately objectionable deficiencies, I would make it a 4-1/2. We had a tendency on that to overshoot the altitude slightly at the initial start. It didn't seem very realistic that you would get such a climb. We got nearly 10 feet of climb out of the thing on the initial start as we nosed it over. There's a tremendous amount of power in the helicopter, but we had really no way of telling. It was nothing that was unsafe or anything like that, but it was more difficult to maintain the 25-foot height. It seemed to accelerate out fairly slowly because of the 60 knots, and then also decelerate slowly to arrest the rates. This seems to have happened not as fast as what it has on some of the configurations. This added to the difficulty of the maneuver. It's a matter, I think, of the pilot learning how to use the energy that he has built up at the end in order to compensate for that, and how to take out collective or use the collective and the pitch attitude to reduce the acceleration rate. It didn't seem like the pitch attitudes and the motion that you got were real to the real life situation. You should have more motion to the high pitch angles that we were getting there at the end. It didn't feel like we pitched up very much at all.

[Comment card:] Is flying technique modified because you're flying a simulator? Same answer as before, yes. There's a certain amount of aggressiveness that you could do in a simulator that you wouldn't be able to do in real life. Aircraft response in this particular configuration? It seemed a little sluggish yet easily controlled. In fact, it seemed almost too-easily controlled compared to a real helicopter. It was a very stable platform. Motion cues? I think the cues to be of some value, but not very realistic. Like I mentioned on the dash/quickstop it just didn't some like we were getting enough G forces in motion cue on that. Motion cues, and how you felt about the other systems? We mentioned that before, but this is the first time I noticed that it seemed like it pivoted around a center-of-gravity point, and then started a translational movement, where the other one seemed to move everything at once. Did motion and visual cues seem to be consistent? Yes, fairly consistent. Any unusual, conflicting, or uncomfortable visual cues? Probably just the deceleration-cue at the end of the quickstop, and possibly the bobup/bobdown maneuver where it sort of seemed like it got out of sync with the motion and the visual. Feeling of discomfort? No. Obvious deficiencies in the visual scene? Again, the lack of definition and texture and lack of perception is the biggest detriment to this visual scene.

Configuration D (ACAH)

Run 700 (Hover). Controllable? Yes. Adequate performance attainable? Yes. Satisfactory without improvement? No. I would make this deficiencies warrant improvement. Minor but annoying deficiencies, an HQR 4. What I found in this is that it wasn't a level of difficulty in getting setup. Once you got setup, it didn't want to drift off. It was fairly steady around the hover point; however, in getting setup, there were significant delays in the system. From the time that the control input was put in, to the time something happened, it had a tendency to PIO a little bit. I noticed that along the later portion of the minute, that it had a tendency to drift forward a little bit. I noticed

that we got bobbling around the hover point so that would degrade the demands on the pilot, and make it more demanding so you had to correct for that.

Run 701 (Vertical Translation). Controllable, yes. Adequate performance is attainable with tolerable pilot workload yes. Satisfactory without improvement? No. I'd say that there's minor but annoying deficiencies. Desired compensation requires moderate pilot compensation. An HQR of 4. Again, the same comments as the minute-hover task. It looks like around the 10-foot point, the 30-foot point, and back to the 20-foot point, each time you go to get stabilized there seems to be a bobbling attitude of the helicopter. It's difficult to maintain a stable attitude at these points, and it appears to be the delay in the control system that's causing the problem in PIO tendency. I also noticed that during translation away from the point that there was a tendency to lose sight of the point. This was mainly due to the late control input that we got as we climbed up or down the diagonal.

Run 702 (Slalom). Controllable? Yes. Adequate performance is attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Minor to moderately objectionable deficiencies. It's somewhere between desired and adequate performance on this one, requiring moderate to considerable pilot compensation. I give it a 4.5 on this. The thing I noticed, it was difficult to maintain a precise track around the pylons this time. I think it felt like it was the overshoot of the control system. You never knew how much you were actually putting in as you went around these pylons out there. As a consequence, you had a tendency to slide around them, and be very jerky in your controls, and not be able to maintain a precise ground track through the course. As we got out to the ones that were further spread apart, it was easier, obviously, since you didn't have to make as drastic or radical changes in the control inputs. Altitude was fairly easy to control, but it didn't seem to be too much overshoot on that. Speed seemed to be easy to control. It definitely was degraded from the condition that we had yesterday. It just didn't seem as stable as compared with the configuration we had before.

Run 703 (Bobup/Down). Controllable? Yes. Adequate performance is attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Moderately objectional deficiencies to very objectionable deficiencies, a 5-1/2, requiring considerable to extensive pilot compensation. This really had manifested itself in overshoots and bobbling around the hover point. This occurred in both the bob-up and the bob-down. There seemed to be quite a bit of oscillation in the vertical axis. Not too much in the horizontal translational area as compared to the vertical. It just seemed like the whole thing lagged the collective input considerably, and made it difficult to hit the target points that we were trying to hit. For some reason the long time delays seemed to be worse as we came down. Whether that was due to the influence of the visual pattern from the ground, or just the fact that we got more momentum going down or maybe a faster-rate vertical velocity as we descended. In general, it seemed like the motion sense was greater. There was higher negative G force and positive G force in this than what it's been in some of the other motion systems.

Configuration E (ACAH)

Runs 704 and 705 (Hover). Controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Moderately objectionable to very objectionable deficiencies. I'd say mostly this is a degradable work level to give it a 5 to 5-1/2. I think adequate performance was attainable, but I don't think you could do movements around the hover point too sharply or abruptly due to the delays from

the control system. It's almost so much delayed that you're starting to PIO, but it still is difficult to make small changes to the position of the helicopter, and like I say small corrections weren't difficult to make. I would give it an HQR 5 on that instead of an HQR 5-1/2.

Run 706 (Vertical Translation). Controllable? Yes. Is adequate performance attainable with tolerable workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. Moderately objectionable deficiencies. Adequate performance requires considerable pilot compensation. HQR 5. It's basically the same comments as we had on the task with the previous control system, except it magnified the comments by a factor of 10 on the stability portions around the hover points of the 10, 20, and 30-foot points. Once you got it going on a trajectory, out away from the cones, it was somewhat easy to hold because it just didn't gain that much. Making the fine corrections to keep on the path that you want to go on, that's what made it difficult, and it was just that much worse than the last configuration.

Run 707 (Slalom). Controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. Deficiencies warrant improvement. I'd say it'd be moderately objectionable, but very objectionable in that considerable to extensive pilot compensation, a 5.5. It almost verges, I'd say to a full 6. The thing I found on this was that it is really difficult to control it around the path. This was very difficult as it was in the previous configuration around the poles, and to make any kind of positive change effective. This was even noticeable on airspeed, on correcting for airspeed, and altitude. It was a definite lag in the system on making changes. When you are maneuvering like this, the change may not even take affect until you're ready to maneuver again so you're really way behind in the maneuvering of this particular type of course. It seemed once you got where you needed to go fairly stable, but getting there was difficult to do, so that's the reason for the low HQR rating on it. You just didn't know how much you were going to get as far as change goes, and there were some points where you found your bank angle was stopping almost entirely, when you really didn't want the change in bank angle to change that much. You wanted it to continue on, but due to the delays you couldn't precisely command the kind of bank angle that you wanted. It also felt like it was uncoordinated going around the turns throughout. Like you're just sliding around the turns, and even putting in pedal input didn't seem to correct this. It still remained uncoordinated.

Run 708 (Bobup/Down). For this I would say that we're just barely getting performance so I would say: Yes, it's controllable. Adequate performance with tolerable pilot workload? Yes. For a lack of a better category that I would give it a satisfactory without improvement, no. Very objectionable but tolerable deficiencies. Not really, it's verging on a 6 to a 7. There's such a big difference there where one says adequate performance requires extensive pilot compensation, and the next ones says you can't attain adequate performance at all with maximum pilot compensation. I'd say that it's adequate performance is attainable with maximum tolerable pilot compensation. You don't have a category for that. The thing I'm noticing on the control system is that it's very delayed. When you put a control input in and it finally takes effect it's very rapid in taking effect. What happens, like in the bobup maneuver, you'll bobup. When you go to take out the control, thinking that you're going to overshoot slightly, all of a sudden you'll go dead in the air. You'll come to a complete stop, and this consequently has made it very jerky in stabilizing out at the hover boards at top, and the same thing down below when you decrease your collective. You establish a rate going, and then when you go to correct for it at the bottom, it all of a sudden stops. I noticed that we were coming out leveling off high, a lot of the times, like 20, 25 feet in the air, and then you had to inch your way down. I think this was also manifested in a lot of the other systems, but not to the great extent of what it was here. There was a lot of controllability given to you late. A lot of control input

that was there, resulting in control effectiveness that just appeared late. Consequently, you had a very jerky movement even in the hover part of this task. Lateral and longitudinal tended to be jerky.

C. PILOT G

Baseline Configuration (Fixed Base)

Run 501 (Hover). Okay, it's controllable. Adequate performance attainable. Is it satisfactory without improvement? No. I find that it takes quite a bit of pilot compensation to really do it hummingbird-like. I find if I concentrate too hard I overcontrol it. Things start to wander a little bit. I'd call that minor but annoying deficiencies. I give that a 4, and that also goes along with the moderate pilot compensation so I call that a 4. On the visual? The visuals were good all around.

[For VCRs:] I get good attitude cues even though I was overcontrolling it a bit, I felt that the attitude cues were good. I'll give that a 1. Horizontal and translational rates, I'll give that a 1. Vertical translational rates, a 1. All around there was good cueing there for that precision hover task. That's the end of my comments.

Run 502 (Vertical Translation). I have one initial comment before I rate the thing here. I did achieve the target altitudes, I think. That criteria was met, and I think the heading was met. I found as I got up to 30 feet the aircraft kept wanting to drift forward. As I looked down, I wasn't keeping a good scan going, and maintaining pitch attitude out the window. It has nothing to do with the visual display at all, but it's just something I'm commenting on. I feel adequate performance in all honesty was not attained, so I have to start there. Everything else, I think, was met, but the aircraft drifted forward. Is it controllable? Yes. Adequate performance attainable? No. I hate to rate this a 7 just for that one little characteristic, it doesn't make sense. What it's saying is, Is adequate performance attainable with a tolerable workload? Adequate is outside the desirable boundaries, but still within the adequate. Adequate is saying that if you keep the cone within the right window 50% of the time, and if you maintain your heading within plus or minus 10 degrees you're in the adequate range. Okay. Basically what it's saying is, if you do adequate performance with a tolerable workload, then you have to go up to at least a 4, 5, 6, and then you ask yourself the other questions there. Is it satisfactory without improvement? We're commenting here on handling qualities, and I think it's just my pilot judgement here, but I'll just go ahead, and be consistent, and say that it's minor but annoying deficiencies. Moderate pilot compensation is the key there. If I had paid more attention to my attitude by scanning back and forth, I probably wouldn't have done that. I'm going to rate that a 4. We have excellent cues from the visual system.

[For VCRs:] Those will be also 1's. They will be similar ratings, 4, 1, 1, 1.

Run 503 (Pirouette). I met most of the desired performance, however, I think I clipped it a couple of times so I'm going to have to put myself again in the adequate performance. I think I was a little bit high a few times. It was very close. It just looked like I clipped it a few times, and then I started moving myself back down low, and it was okay after that. It's mostly adequate so we'll just do it that way. It's controllable, and tolerable pilot workload although it's demanding. Satisfactory without improvement? None of these I consider to require minimal pilot compensation. At least the workload is fairly intense, racing around there in 45 seconds so I'm having a hard time getting above the 3-1/2 boundary. Okay, I'm going to have to give you a 4 again. Again, there's moderate pilot

compensation, and again the visual display is doing a real good job. I don't see anything there that is causing any problems.

As far as cueing, I'm getting good vertical cueing here. Horizontal translation rate, the rates which I require to maintain my bank angle, attitude, etc., are all good so I'm going to give you a one across the board on that. So again, 4, 1, 1, 1.

Runs 504 and 505 (Slalom). There's such a wide margin of criteria here between desired and adequate — don't hit the poles, don't fly into the ground. I found in my critique of my performance here, I probably had the altitude, and I didn't hit the poles, I had those things right. It's just that the airspeed was poor all the way through it. I have to say that I meet the adequate performance. Starting there, going through the HQR: Controllable. Adequate performance attainable with a tolerable pilot workload? Yes. I find this probably to be the hardest task so far. I'm not up to speed, my learning curve is not up there yet on this one so I'm going to rate this a 5.

The VCR rating here? I'm not aware of anything in the way of visuals that's causing this problem that I might be having. I think it's just a matter of controllability of the aircraft, just me, and not keeping the attitude where it should be. I don't think it's because of the attitude information I'm getting from the display. It could be, but I just can't say that; however, I'm going to mark down because I did have a hard time maintaining attitude through the course, I am going to give a 3 because I'm not aware of the problem. I do have a pitch attitude problem so I'm going to rate the attitude rating a 3, fair. The horizontal translation, a good 1. The vertical, I rate that a 2.

Run 506 (Bobup/Down). It is controllable, and attainable. Adequate performance is okay. *Satisfactory without improvement?* We're trying to evaluate the vehicle when really there's some things about the task that make it difficult no matter what you would be flying here so it's iffy trying to determine aircraft characteristics as a basis of your rating here. Again I'm having a hard time saying it's minimum pilot compensation. This is a task requiring considerable so it's down to deficiencies warrant improvement. I'll make a right turn there, and moderate pilot compensation describes what I'm talking about so I'll make that an HQR 4.

For the VCRs, I'll give it a 1 across the board here because I feel these cues are excellent. Vertical is really required here, and the horizontal is hard to perceive. I think that's just because in a real world it's hard to perceive. We're getting good horizontal translation cues, and of course attitude seems to be adequate so I'm going to go three goods on that so 4, 1, 1, 1.

Run 507 (Dash/Quickstop). It's controllable. Adequate performance attainable with a tolerable pilot workload is a yes. Okay, I'm going to, for the first time here, jump across a 3-1/2 border, and satisfactory without improvement I'll put down yes and give it a 3.

On the VCR, it's already indicated. I saw in attitude a pitch retching as I nose the aircraft down, and it was real bad. I'll give you a poor 5 on attitude for that specific reason. Only that one point in that maneuver. Everything else was okay. Just for the initial rapid pitch rate nose down. Horizontal vertical translational rate, vertical translational rate a 1, 1. So that's HQR 3, 5 on attitude, and 1, 1 on the other two.

Runs 508 and 509 (Sidestep). I probably got the heading okay, but I know the altitude — I saw 5 on there once, right towards the end, I think I'm just getting tired. I did not maintain within the desired performance, I know for sure. However, I did meet the adequate performance, I didn't hit

the ground. Okay, it's controllable certainly. Adequate performance with tolerable pilot workload? Yes. However, it's not satisfactory without improvement, and I'm going to rate this a 5. I feel that adequate performance requires considerable pilot compensation. This is one task that I never have done really well on, and I've done a lot of lateral quickstop maneuvers in airplanes and simulators over my career. I just can't do this one that well. There's a problem here somewhere. I know I'm tired, so I'll go ahead and give that a 5.

For the VCRs, the attitude information I'm getting, and translational, the rates, the vertical translation, those all look okay. I'm having a hard time maintaining the criteria here. Three 1's.

Baseline Configuration

Runs 510, 511, and 512 (Hover). I found that the task was done quite easily. I had very little problem. I tried to concentrate on not putting in any inputs at all, and I only made small ones, and etc., and that was my control strategy. It was definitely controllable. Adequate performance attainable. It's satisfactory without improvement so it's up in the Level 1. I think it had good characteristics. I had to concentrate to keep it there, so I wouldn't give it a 1. I'll give it a good with negligible deficiencies with pilot compensation not being a factor so that's a pilot rating of HQR 2.

As far as the VCRs go: Attitude cues were very good. I give that a one. Attitude cues were very good, very clear, very precise. I could pick up very small attitude, and that led to good horizontal and translational rate cues. A lot of texture, etc., out here to give me a very precise indication of small movements so I give that VCR 1. Vertical translational cues were also good, so I give that a VCR 1.

Run 513 (Vertical Translation). No problem getting established, and climbing up to 30, and then going down to 10, and up to 30, coming back down to 20 again, it took a little while for me to get squared away. I started to move forward, but I feel I met the desired performance; however, the compensation requirement was definitely greater. Looking at the HQR: Controllable. Adequate. I still feel that performance was satisfactory without improvement; however, some compensation was required, especially coming back down to establish the 20 foot hover altitude. I'll give that an HQR 3.

As far as the VCRs are concerned, 1, 1, 1 on all three of those. Same cues were used, and they were still very good.

Run 514 (Pirouette). I feel I met the desired performance criteria on the pirouette. It takes a lot of concentration. A couple times I started to get outside my intended circle, but certainly controllable. Adequate performance attained. I say it's satisfactory without improvement, and I'm going to give it an HQR of 3. Minimum pilot compensation required.

I'm going to give 1's for the three ratings for VCR for the same reasons that I stated before. There's very good visual cueing there.

Run 515 (Slalom). That also went along okay with desired performance. That went along well. Pilot compensation-wise, a lot of concentration. I always consider you have to put a lot of concentration in the maneuver. You're probably compensating for something although it's just a matter of judgement. It's certainly controllable. Adequate performance attained. I'll say satisfactory with minimum pilot compensation, so again I'll say that's an HQR of 3. I found when I practiced it

fixed-base the other week, my airspeed was just all over the place. Perhaps the motion is helping me here, but I'm able to control the airspeed much better than I did before. It's probably practice, but the concentration was just in maintaining that attitude.

[For VCRs:] There's good cues visual-wise for all three of those. Attitude is important for speed control, and I thought my speed control was okay so that was good, so I'm going to give 1's for all three of those again. They were good in each case.

Run 516 (Bobup/Down). I think basically the desired performance was met so I'll base my comments on that. Okay. Controllable? Yes. Adequate performance with tolerable pilot workload? Yes. Satisfactory without improvement is the question here. If you look at the airplane itself the height control is the big thing here. The damping, etc., seem to be adequate, and satisfactory. The question is how much pilot compensation? You have to anticipate when you reach the top target, and anticipate when you're coming down. Are there any deficiencies involved? Let's see, desired performance requires ... I'm right at the borderline. Since I can't give you a 3-1/2, I'm going to go ahead and give you another 3 on this. HQR of 3.

The same with the VCRs, they're all good. I didn't see anything out there in the way of glitches or characteristics that were causing me to back off on my aggressiveness in my performance, and etc. I felt that the visual cueing outside was very good. I've done this task in the real world, and it's the same. The visual cuing here is the same as the real world.

Run 517 (Dash/Quickstop). My assessment of how well I did here. I got it started. I could have stopped it at the right place, and initiated there. I got the right airspeed. I was concerned about my altitude, it was within 15 feet. Pretty much in all of the desired performance criteria so I'll assume it was. HQR. Controllable? Yes. Adequate? Yes. I didn't really see any deficiencies. Okay, I'm going to lead this in to a Level 1, so I'm going to give it another HQR 3.

On the VCR's the same as before [1, 1, 1].

Run 518 (Sidestep). Desired performance was met. Okay. Again, it was controllable. Now, this is the one I usually find I have the most trouble with, and I really need the compensation, and I don't think it's the handling qualities of the airplane. It's just judging things out here. It might be visual cues so it's controllable and adequate, but I'm going to rate it down. It's not satisfactory without improvement. Moderate pilot compensation required. I give it HQR 4. I'm having some problem with judging where to stop and start, where the boundaries are, and also the altitude control here is a little bit of problem for me. Those are the compensation factors that I'm talking about here so HQR 4.

[For VCRs:] Height, again the visual cuing is good. Perhaps what I need is a little bit more of texture. Let's see. For attitude I'm going to give it a VCR 1. For the translational rates, I'm going to come down, and give that a VCR 2. For vertical, especially out at the sides where I don't have any vertical tower to look at because it's not in my front view, I'm also going to give that a VC 2.

[Comment card:] Is your flying technique modified because you're flying a simulator? You always have to answer yes to that. Always. You know you're willing to be a little bit more aggressive on a simulator. That's what I mean by that. Sure it's modified. You're not as concerned about breaking the airplane, although this simulator you could break it when you're in motion. The

explanation is, yes, usually always because it's not the real world. You don't have the real world risk, etc. I try to use the same strategy when flying, but the answer is down to the technique, and it's definitely modified to a degree. Hope that answers your question. Aircraft response is good. It's not sluggish. Unusual characteristics? No. Motion cues? I find the big thing I really want to say is I did fly fixed base during the first session, and I realize I'm still probably going through a learning curve experience. I found the motion today, once we got it all squared away, to be very valuable for control. I don't think I could have gotten done anywhere near as good in this lateral quickstop without motion. The accelerations and the decelerations, for example, the good kick-in-the-pants feeling gives you good feedback for initiating acceleration, and initiating the deceleration, etc. So, I say, the top one is valuable for control. Okay, I can't compare this motion system with others, this experiment, not yet. The motion and visual cues seem to be consistent. I didn't sense any phasing or any of those kind of problems where there was confusion between what I saw, and what I felt. Is there any unusual, conflicting or uncomfortable visual or motion cues? None that I was aware of. I felt, again, they matched well, and they assisted me for the visual, but the motion in particular was a real asset here. No discomfort, disorientation or sickness or any of that stuff. Obvious deficiencies in the visual scene? The only thing I've detected on this is when there's some real rapid moving. I saw it when I was doing fixed base runs the other day, but I didn't see it today on the acceleration when I pitched the nose down. I got kind of a chattering or a stair-stepping effect. I didn't see that today so no, I didn't see anything in the visual scene that was a deficiency.

Baseline Configuration (Modified Motion)

Run 520 (Hover). First of all, on the free time, just evaluating, getting used to the new motion system, I didn't see anything in there that was a concern as far as giving me false indications, out of phase, or anything that would degrade my evaluation of the motions of the aircraft. I did run into some stops a couple of times. They weren't violent encounters, but nevertheless, they were there. They didn't seem to bother me too much. All in all, I thought the motion system felt okay. The hover evaluation: I believe I met the performance criteria. As far as HQR it's going to be good, because the pilot compensation there was very low as far as requirement. I'd say pilot compensation was not a factor. There was very little to do. Just concentrating on not putting in any control inputs at all. If you do put anything in, just small ones. So, is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? Yes. I would call it a good, which is a 2.

VCRs: Again, I feel that the VCR rating should indicate a good condition here. Attitude, which was very important here, because very small attitude changes would cause a drift, attitude and horizontal translational rates were both good. I could pick those up very quickly, and it was good information. It was also good for vertical. It's good across the top with three ones. So, it's 2, 1, 1, 1.

Run 521 (Vertical Translation). It was desired performance. The heading may have gotten off. It may have reached 5 degrees. It didn't go much beyond that so I feel that I maintained the desired performance criteria. I still find this, even though there's not much going on, I tend to drift either fore or aft when I do this climb or descent. That is too much. However, on the HQR: It was controllable. Was adequate performance achieved with tolerable pilot workload? Yes. It's satisfactory with just a little bit of concentration on trying to maintain my attitude precisely to keep from drifting in the fore and aft directions. I'll call it minimal pilot compensation. It's not moderate so it's a 3 on the HQR.

VCRs: Again, the VCRs were good. In this case, perhaps I should change my thinking on this. I keep mentioning I'm drifting fore and aft, and I don't know just what it is that is causing me to be a little bit behind on making the pitch corrections. I don't want to put in too much. Just to indicate that I'm having a little problem with the translational, I'm going to rate the attitude a 2. The horizontal translational rate a 2. The vertical translational rate a 1. That's a 2, 2, 1 on those with an HQR 3.

Run 522 (Pirouette). First question, is desired performance met? I believe so. Of course that pirouette display out there is quite good. It gives you a lot of information both for vertical as well as lateral fore and aft positioning. The task was relatively easy to perform. So, on the HQR: Controllable. Was adequate performance attained with tolerable pilot workload? Yes. Let's see... how much concentration am I putting in this thing? I know you're going to be rating these motion systems here based on these things. I don't want to be inconsistent, but since you won't take a 3-1/2, I'm going to have to rate it a 3 or 4. Was it satisfactory without improvement? I'd say it was satisfactory without improvement. I'm going to give it a 3 with minimum pilot compensation, so HQR 3.

The VCRs, as I mentioned before, there's good cues out there. The ring to follow you could see. You could see down, you could see out to the sides pretty well, so I had good indication of in and out positioning as it went around the ring, so those were all goods. Good for attitude, and horizontal translation, and vertical translational rate. All were good, so 3, 1, 1, 1.

Runs 523 and 524 (Slalom). The desired performance was met this time. That's a task where you're in and out of the cockpit. For altitude, I'm depending on the visual outside. For airspeed I have to look inside. I'm catching my glances back and forth, inside, outside. The information I'm getting is of course the information I need to maintain the desired performance, so that says good things about the display, and the motion cues that I'm getting. As far as HQR: It's controllable. Was adequate performance attainable with tolerable pilot workload? Yes. I would say if there is any annoying deficiencies, the tendency for the aircraft to slow down and speed up as you roll it and turn it through the slalom is there. I'll say it is not satisfactory, I'll say a no, and give it an HQR 4. There is that requirement to compensate for the airspeed changes with some pitch attitude inputs to correct for the tendency to either slow up or speed up in rolling out of the turns. HQR 4 for that.

As far as VCR's go, I believe this is a fairly aggressive and precise task. I think it's a good test for that, and certainly I can do it within the desired criteria, so I would give it a good rating. I think I'll mark down attitude. Flashing by those poles like that, there's a little bit of confusion as to what my attitude should be. You really can't call it a visual display problem. Using the VCR rating system, just calling it for what it is here, I'm going to go ahead and give the attitude one a 2. Of course translational, there's a very good feel for your velocity, so I'll give that a 1. The poles give you good vertical translational rate information, so 2, 1, 1.

Run 525 (Bobup/Down). That's a demanding task in one axis there. It's controllable. Is adequate performance attainable with tolerable pilot workload? Yes. I feel that the height control, which this is all about, the damping, etc., all looked good. I wouldn't know how to improve it any more than it is. It has good handling qualities, nothing limiting there. It's satisfactory without improvement, however, it is a demanding task. In previous runs, my comment has been to try to keep my distance in and out. I call it range. It could be a problem because you don't have much cueing until you get up to the target to tell you whether you're drifting in or drifted back. That's more of a VCR problem than it is a handling qualities problem. There is an associated compensation

required, so I'm going to go ahead and rate that a 4 because of that. Not the vertical task, but the maintaining the range or the distance from the target especially when it's out of view, so HQR 4 on that.

On the VCRs, to reflect my comment on attitude, it is down a little bit, I call it 2 on the attitude. Horizontal translational rate, that's the one, I'm going to give that a 3. This is a little different than what I gave before, but I'm just having to call it as I see it here. Vertical translational rate is good, I call that a 1. It goes 2, 3, 1. This is the first one where I've seen something different in each case.

Run 526 (Dash/Quickstop). Very comfortable. The motion system felt very good. I got some good cues. I feel like on all of these the motion system has been reduced a little bit. That is, it's been washed out more. That's just the kind of feeling I get through most of these things. The HQR on that is going to be good, Level 1, because it was controllable, certainly adequate, and satisfactory. Minimal compensation required, so I'm going to give that an HQR 3.

The visual cues: There's one thing here that I probably should have pointed out in my earlier discussions on the VCR, and that is the attitude cue here. I've been looking in the cockpit because when you push the nose over, you lose the horizon on this simulator. That's something I should have pointed out before, so attitude wise it's not a 1. All the other attitude cues from then on are all okay. I believe I graded it down once before, for a jitter when we were doing the fixed base. I didn't see any of that. The only thing you do typically on all of these CGI's, you lose the horizon if you pitch the nose down the way I did there. Because of that one particular characteristic, I'm going to rate this down to a 2 for attitude. Horizontal translational rate and vertical translational rate are all good with the poles out there to give me some altitude. I certainly sense I'm accelerating and decelerating. A 2 on the attitude, a 1 on the horizontal translational rate. On vertical, I don't think I'll rate it back down to a 1 again. In fact, I'm going to give it a 3, because as I decelerate with my nose up high, I really am not quite sure how high up I am. I look out to the sides like I would in a helicopter. I feel that if I had a real world out here, I'd have more information with which to judge altitude so 2, 1, 3 on this one.

Run 528 (Sidestep). Controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? That's a difficult task. I've always had problems with this one. I'd say no. Moderate pilot compensation required, so I'll give that an HQR 4. I think a lot of it might have to do with the visuals. I think I made this comment on my previous set of runs with respect to VCRs. Altitude is difficult to assess when you get away from that little donut sitting around the pole out in front of me there. It's easy to drift down or climb if you don't have the resolution, don't have the texture, etc., that we have in the real world. I feel the vertical translational rate cueing is lacking here. The horizontal translational and the attitude are good. It's roll attitude that we're looking at here, and also some pitch. I think pitch and roll attitude are well represented here. We can see it, but altitude gets out of hand.

For the VCRs: On attitude, I'll give it a good. Translational rate, because we have these squares and things out here, I'll give that a good. For vertical translational rate, altitude control, I'll give it a 3, mark it down. It's good when you're going by the reference out there. It's not good out at the ends, where you have to make the quickstop. That's where the pilot workload goes up.

Pilot comment card: Is the flying technique modified because you're flying a simulator? That comment remains the same as the one I gave you already. You always modify it because you're flying

a simulator. I know the question here is really pointed towards, is there something about the simulator you don't like that's caused you to modify your flying technique? No there isn't. It's just the generic one. While I'm in the simulator I tend to be a little less concerned about safety. We're not supposed to do that, but that's really the only thing. The flying technique is modified. I can't really put it in any descriptive way, other than, it may be less incentive to keep the airplane from crashing. It's nothing that the simulator in the way of visuals or motion is causing it. Now, if I were flying backwards, in an area where I can't see, then I would say yes. All of these tasks seem to be ones where we can see where we're going, but there's not a problem with motion or display. Comment on aircraft response? Nothing unusual. It's good. It's a Level 1 airplane. How did motion cues affect your control of the rotorcraft? I thought they were valuable for control. I think I talked about that before when I went from fixed to motion, how much better it was. Is it more valuable than the motion system of the last one? I can't answer that. Perhaps there will be another question down here that I can address the comparison to. Compare this motion system with the other one flown. I sense from my initial evaluation, as well as going through these formal evaluation tasks, that you have washed out some of the motion. Maybe it's set up, although I did get a couple of cues, that I did run into some stops. It sounds like this one is designed for the low frequency tasks, and not the high frequency. I like it. This is fine. I thought the motion system gave me good cueing compared to the other one. It looks like a little bit less in the way of rates for initiation, like the roll reversals, the accelerations and the decelerations. Did the motion and the visual cues seem consistent? Yes. I didn't see anything in the way of conflicting information, or out of phase. Were there any unusual, conflicting, or uncomfortable cues? No, there were not, so there's none to describe. They seem to compliment each other. No discomfort, nausea, or disorientation? Nothing like that, did I sense. Obvious deficiencies in the visual scene? Other than the usual one, like out over the grey area, there's no texture, and you can't tell how high you are. Other than that one, I can't think of anything else. They seem to be behaving themselves. I didn't see any jerkiness, any skips, any artifacts or anything like that. Basically the answer to #8, no obvious deficiencies.

ACAH

Run 530 (Hover). That was a very easy task that had very little to do with the attitude system. Very little drifting around. Very relaxing. I achieved the desired performance without any doubt or concern. HQR, I never get 1's , but I'll give it a 2, HQR 2. It was controllable, adequate, and very satisfactory so over to the right, and negligible deficiencies, a 2. No pilot compensation. I didn't see anything in the visual, or feel anything in the motion that was distracting to me.

VCR — good cues all around, on all axes so it's three 1's.

Run 531 (Vertical Translation). I used a different technique this time, as instructed, to go ahead and do the simulated landing task as rapidly as possible. My precision certainly went downhill, and I had to compensate to decrease the time for performing. As compared to my two practice runs which I used, I took my time, and the workload was low here. Rushing it a little bit, the work load was higher, however, it was controllable, and it was adequate. One time the end of the cone bounced out of the lower right hand corner of the window. It went back in again so adequate performance was achieved. Satisfactory without improvement? I'm going to say no. Minor deficiencies and moderate pilot compensation, and this is with the presented requirement to do it as rapidly as possible, so HQR 4. The motion felt fine.

[For VCRs:] I did have some problems trying to be aggressive so I'm going to rate all those things down. I would have given them 1's, but possibly the visual cueing was partly responsible for my increase in pilot compensation there so I'll give attitude a 2, the translational rate a 2, and the vertical translational rate a 2.

Run 532 (Pirouette). This is one of the tasks where the attitude system improves the accomplishment of the task, reduces the pilot workload. Holding the attitude, holding steady rates, and holding the pitch attitude required the whole of the circle, and the bank attitude to maintain the velocity, etc., was improved. It was certainly controllable. Adequate performance was achieved — two seconds over on one, and everything was okay. Satisfactory without improvement? I would say yes. This is a task that really requires some concentration, and I feel a degree of pilot compensation. It's just a matter of sensing whether the airplane is starting to fall out of the circle or slow down. Make sure your heading rate maintains the airplane pointed at the center, etc. Pilot compensations are required in all of that. Certainly, in coordination, so minimal pilot compensation sounds right, and I'll rate that an HQR 3.

This is again a task that has good visual cueing. The little altitude indicator, I call it a donut out there, and the pylons are something that you can really see. The markings around that are on the ground, they are nice and wide, and you get good cues for position as well as velocity. Attitude looks good. You can certainly sense rate changes, range changes, etc., so I'm going to rate those all good so 1, 1, 1.

Run 533 (Slalom). That looked better. That's the best run that I've made. It took two practices to realize that I need to be a little more aggressive in putting in the roll inputs. Instead of having a rate system, I had an attitude system here. It required larger stick deflection so that was within the desired performance level. I also found out the attitude system assisted in maintaining airspeed so that helped there. It was controllable, and adequate performance achieved. Was it satisfactory without improvement? It looked awfully good to me. Again, there's this question of performance requiring moderate pilot compensation, I'm on the borderline here, between 3 and 4. Certainly the handling qualities of the aircraft were very good, and they don't require compensation. The task is a difficult one, but I didn't come close to hitting anything so considering those two things, it is satisfactory without improvement. I'm going to give it a 3 with minimal pilot compensation.

The visual cueing, again, was good. You had these pylons sitting up here, certainly, they give you good altitude cueing. Attitude cuing probably is a little more difficult because the poles are going by, however, is that a function of our display or a function of just nature? Translational rates were good so I'll give you a 1 on that. I'm going to give it a 2 for attitude. It's a 1 for the horizontal translation, and 2 for the vertical translation.

Run 534 (Bobup/Down). I guess of all the tasks this one probably requires more anticipation or pilot compensation than all the other ones, but it's also not a function of simulation factors like motion and/or visual. In a real world it's a fairly difficult maneuver to perform rapidly because of the nature of the thing. You're sort of standing up in the air where there aren't a lot of cues until you get up and see the target. Okay. It was controllable. Adequate performance accomplished. Is it satisfactory without improvement? A lot of compensation required here. I'm going to say no, deficiencies warrant improvement and give it a 4. Moderate pilot compensation, minor but annoying deficiencies.

The VCR's. The attitude cueing, because you're kind of up and away from things, the horizontal translational rate cueing, both of those are towards the poor side of good. The vertical translational rate is good, so I'm going to give that a 2. For the attitude, I'm going down to a fair. For the horizontal translational rate, a fair. The vertical translational rate a 2.

Run 535 (Dash/Quickstop). Certainly it was controllable, and adequate performance was attained. Satisfactory without improvement? I would say yes. Pilot compensation is a factor, primarily in judging altitude variations with the nose in the pitchdown for the accel, and pitchup for the decel. Those two conditions, both the beginning and the final part. A lot of compensation. Some compensation is required which I would consider not moderate, but I'll call it minimal. So I would say satisfactory without improvement, yes. This is a really good system for this kind of maneuver, so I'll give it an HQR 3.

[For VCRs:] Now once more with the pitchdown and the nose high attitudes for accel/decel, there's a lot that you can't see outside. You really depend on those poles for some of your cueing. Horizontal translational rate cueing is fairly good, I'll give that a 2. The attitude cue I think is pretty good. I can look out to the sides from the cab here and pretty much judge where the nose of the aircraft is. I didn't see any ratcheting when I pitched the nose down this time. I think I did see it once, and rated it down for that so the attitude was pretty good. The vertical translational rate is between fair to poor. Attitude a 2. Horizontal translational rate a 2, and the vertical translational rate, altitude judgement, I'm going to give that a 3

Run 536 (Sidestep). I see the altitude requirement is maintained plus or minus 15 so that looked okay. Alright, I feel I performed it with the desired performance level. I feel that this task is probably a combination. That is, it's sort of in between. It's not a high frequency task, it's not a low frequency task. It's kind of in between which has a little bit of both in it. I feel it's a good task to evaluate these kinds of things we're doing in this simulation. Okay. It was controllable, and adequate. I feel whether it be the motion, the visual or the handling qualities of the aircraft that it is not satisfactory without improvement. I'm going to give it an HQR 4. Desired performance requires moderate pilot compensation.

As I stated before, the visual cueing here varies. It's good at the center where you have good altitude, attitude, and horizontal translational rate information provided. When you get out to the borders, you lose the vertical translational rate. I feel that degrades a little bit from your performance capability. Attitude wise I'm going to give it a good. Horizontal translational rate a 2. It's 1 and then a 2. The vertical translational rate, specifically out at the ends of where the reversals take place, I'll give a 3.

Configuration E (ACAH)

Run 537 (Hover). It was just identical to the last set that I evaluated. Very little to do. Just sit there, and let the attitude system take care of your attitude. Very little input sent to either the collective or the cyclic so it's a very easy task. Make that an HQR 2.

Runs 538 and 539 (Vertical Translation). I'm seeing something consistent here. I don't see anything visually that is causing any problems that I'm aware of; however, I noticed from a motion point of view if I put in any kind of a significant input in attitude or in height, either one — by significant, I mean trying to maneuver at a good rate other than just sitting there — I then find that I'm going into an oscillatory mode of my inputs. I think it's feeding back to the motion system, and

causing me to sort of PIO even small inputs that I'm trying to make. That's causing me to have to compensate more for that. However, on the landing task it was controllable, and I think I met the desired performance, but fairly high pilot compensation, I mean there was some so it's controllable, and adequate, but not satisfactory without improvement. There were some deficiencies. I'd like to give you a 4-1/2, but it's not bad enough to be a 5 so I'm going to give it a 4. Annoying deficiencies, requires moderate pilot compensation is the key phrase there so HQR 4.

Run 540 (Slalom). Same comments, only to a greater degree as we pick up the frequency of the control task here. I'm seeing an oscillatory response to my inputs. It also appears that I've got a coupled helicopter. It feels quite a bit like a rigid rotor helicopter, like a BO-105, which I have flown through a slalom course similar to this one. As I put in roll, for some reason or another, I'm getting some pitch bobble in there so it's really degraded the apparent handling qualities significantly. It's controllable, and I did keep it within the 35 to 43 knots. I just barely did, but I kept in there. I think the desired performance criteria was met, but it took a lot of pilot compensation to do that. Controllable and adequate, but it's definitely not satisfactory. It needs improvement. I would rate this down to a 6. Extensive pilot compensation, and the compensation is one that looks like an apparent roll in the pitch coupling. For example, if you were evaluating a fair helicopter at some facility that had this kind of thing that you have in here, whatever it might be, the pilot might get a wrong impression as to the handling qualities of the aircraft, and it might be the simulator itself. That's the problem.

Run 541 (Bobup/Down). In the desired performance you should be 10 feet or higher above the ground, and on the adequate you can be as low as 5 feet from the ground. I was sort of in and out of the desired, but never quite got to worse than the adequate, so I'm going to take all of that in consideration. I feel that this same characteristic I'm feeling in the motion system is causing me to overcontrol this vertical path. It's a very aggressive task, and I'm coming up to the top overcontrolling then coming down the bottom and overcontrolling. Stretching the desirable performance limits here, running through them, and considering all of that it is in fact controllable. Adequate performance attainable with tolerable pilot workload? Yes. Deficiencies do warrant improvement. We're somewhere in Level 2, but very close to 3. I'm going to give this a 6. I'm using the motion feedback, and it's causing me to overcontrol or it's due to just the characteristics of the aircraft. My inputs, I'm responding by overcontrolling it, and bobbling. The precision is lost because of the oscillatory overshooting.

[Comment card:] It's the same on number one. Well, I'll comment further. Again, I'm not flying in the real world, I'm flying in the simulator so there's some differences there. Just your attitude towards how aggressive you may be, you tend to be a little bit more aggressive. You tend to test the system a bit more by bringing it closer to the edge in control, to an instability that you would not if you're in the real airplane. You're more cautious in the air, in the real world, for obvious reasons so there's where I say the technique is modified. I'm a little bit more aggressive in the simulator. The aircraft response is not crisp. As I said before, it has a bobble, an overcontrol or a ripply response to control inputs. It's not sluggish, but the unusual characteristic is what I've been talking about. A tendency to overcontrol in an oscillatory fashion. How did the motion cues affect your control? I can say that the motion cues affected my ability to control the aircraft in a negative way. I'm second guessing here. I know that you've made some modifications to the motion gains. It's either the aircraft, the motion, the combination of the two or maybe all three. I would say the motion cues certainly are affecting my ability to control the aircraft in a negative way, especially that last one. Compare this motion system with other systems flown? Okay. I like the previous one, the basic system, that was good. The combination of basic motion gains plus the

attitude control system certainly enhanced my ability to perform many of these tasks. Did the motion and visual cues seem consistent? I saw the bobbling that I felt. I did see it. I saw it, I recall, in the slalom. I saw the pitch as I rolled, etc. I saw the overshoot here so, yes, they seemed consistent. Unusual, conflicting, uncomfortable visual or motion cues? No conflicting. Uncomfortable motion and visual would be the bobble type of response that we talked about. Despite all that no discomfort or nausea other than I'm just plain tired. No illness so that answers seven and eight. Obvious deficiencies in the visual scene. I didn't see any obvious ones. I didn't see any ratcheting or any of those that I'm familiar with.

D. PILOT S

Baseline Configuration (Fixed Base)

[Runs 200-206: Comments lost.]

Run 210 (Hover). Is it controllable? Yes. Is adequate performance attained with a tolerable pilot workload? Yes. Is it satisfactory without improvement? I guess I'll have to say, if it weren't for the conditions here we'd just have to say yes there. There's fair, some mildly unpleasant deficiencies requiring minimal pilot compensation for desired performance. It's still an HQR 3 for the hover. What I perceived, a little bit of workload in lateral and fore/aft drift, I concentrated out the side window. Heading got off a couple of degrees just due to lack of cueing, but I saw no major deficiencies in the handling qualities. Normal rate command response.

Run 211 (Vertical Translation). *Pilot's decision: Is it controllable?* The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? This time it was, it was yes. I'd still have to say it's fair, some mildly unpleasant deficiencies. They are very minor. Minimum pilot compensation required for desired performance. I had oscillations plus or minus about two degrees in heading. I just had to increase the workload. It's a high gain task since it was in all four axes, but no major problem at the rates I was doing the task, so I just give it an HQR of 3. If that's aggressive enough, it wasn't that big of a deal.

Runs 212, 213, and 214 (Slalom). Pilot decision here: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? The answer is no. In order to keep the speed up and maintain altitude, especially the way the model's working in yaw, it required a 4-axis maneuver, and in doing so I could only concentrate on two or three things at a time. I think the airspeed got up as high as 50 knots there. Altitude was about plus ten so I think that's out of desired. Consequently, it's probably a moderately objectionable deficiency, adequate performance requires considerable pilot compensation, HQR 5. Major deficiency is I'm getting no weathercock stability or the airplane's not trying to turn in to the wind, so I'm putting a little extra workload in the pedals in the turns. In order to concentrate on maintaining the altitude and the airspeed, I could only do one or the another. Consequently I let the airspeed get away in this case in order to stay above 35 knots, it's just too many parameters to try to maintain at once.

Configuration E (Fixed Base)

Run 215 (Hover). Pilot's decisions: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? The answer is no. We've got a deficiency here that warrants improvement. It's probably a moderately objectionable deficiency. Adequate performance requires considerable pilot compensation, and that puts me at an HQR 5. I was quite involved in maintaining the position. There was quite an amount of activity in the pitch and roll. There were occasional corrections in yaw. Consequently it was three axis pretty continuously, and I let the altitude get away, plus or minus 3 feet, and was constantly in the axis. Not to a PIO state, but constantly in the axis so the workload was considerable, and that's the main reason for the HQR.

Run 216 (Vertical Translation). Again, workload primarily pitch this time. Trying to come up, I'm getting into the roll. Five degrees in yaw. It's much easier as I get up to altitude, 30 feet, back down to 20. Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attained with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. We have a deficiency that warrants improvement. Probably a minor but annoying deficiency that showed up here. Desired performance required moderate pilot compensation. The workload increased as I descended, primarily in pitch, occasionally in roll, resulting in out-of-control inputs. Heave axis was real easy. No real workload there. So, it's HQR 4 primarily due to workload as I got down to the 10 foot portion of the task.

Run 217 (Slalom). Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? That's marginal, but I would still have to say yes. Is it satisfactory without improvement? I'd say no. The deficiency warrants improvement. I'd say it's a very objectionable deficiency. Adequate performance required extensive pilot compensation. This took place primarily on it when I started to initiate the turn. It got into a deceleration which I was trying to keep from happening because this happened every time. It seemed like I was always playing catch up. By the time I got to the end of the course, I was caught up too much, and I think my airspeed was up close to 50 knots. Workload was extremely high in each turn coordinating in all four axes. This required a lot of collective step type inputs to maintain altitude. It took a lot of pedal to keep the nose pointed through the course, and a lot of forward stick in order to keep the airspeed up. There seems to be something in the turns that I'm losing airspeed if I don't keep the stick forward, and then it takes a step input to keep the altitude so a lot of extensive pilot compensation for an HQR 6.

Configuration A (Fixed Base)

Run 218 (Hover). Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attained with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? The answer is yes. It's fair, some mildly unpleasant deficiencies. Minimum pilot compensation required for desired performance. HQR 3. A little workload in the pitch, occasionally in the roll axis to maintain position. Just a tight crosscheck. Maintaining altitude plus or minus a foot wasn't a problem. Drift was probably off as far as the corner of the window. It stayed right within the area it should. It probably drifted plus or minus 5 feet at max, maybe even less. It's not that big a deal, HQR 3.

Run 219 (Vertical Translation). Maybe I'm getting used to these things, I'm not sure. Pilot decision: Is it controllable? Answer is yes. Is adequate performance attainable with a tolerable pilot

workload? The answer is yes. Is it satisfactory without improvement? Here again I say yes for rate command. There was some pilot compensation so it has to be at least minimum pilot compensation required for desired performance. Mildly unpleasant deficiencies is the worst thing I can say. It does become a four-axis maneuver, but heading control was not a problem plus or minus a couple of degrees. Primary workload again at the lower altitudes was maintaining position, primarily in the roll axis, that's where the workload was. A little bit of work also in the pitch axis. That was about it. I give this an HQR 3.

Run 220 (Slalom). First comment is the performance is still kind of hard to perceive in here. Altitude I know is within tolerance, and I think the lateral deviation was within tolerance. Airspeed was marginal. That may have eventually got slow, and I didn't catch it. I perceived it, but I know that I got a little bit fast. With that in mind, I'll say it was controllable. Adequate performance attained with a tolerable pilot workload. Here's where the question comes. I didn't catch that I went below speed, but I'm assuming what I saw. I may have been a little slow, but I'm going to say that I probably got adequate performance, but not desired. I would say, is it satisfactory without improvement? I'd probably have to say no. There's a deficiency that needs improvement. It's probably adequate performance requires considerable pilot compensation, primarily in airspeed control because I'm just not getting much feedback as to airspeed control. I sense that it was dropping, nosed down and tried to accelerate back out, and then again overshot. At this particular speed trying to fly this course it takes considerable pilot compensation in order to try to maintain that desired speed. It doesn't have adequate performance, so I'd have to give it an HQR 5. Additionally, I would say that maybe I've run through the course enough now that the heave and yaw control coordination seems more natural this time than it has in the past. I don't know if that's training or just the control system. I didn't have any problem that I perceived in the heave and yaw control. Primarily just in airspeed control.

Configuration L (Fixed Base)

Run 221 (Hover). Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? Pure rate command, I still have to say yes. Some mildly unpleasant deficiencies primarily in the longitudinal/lateral axes. Minimum pilot compensation required for desired performance, an HQR 3. Again, primarily activity. Small infrequent inputs in the longitudinal and lateral axes for the compensation. That was it. It just seemed sloppy.

Runs 222 and 223 (Vertical Translation). Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I'd have to say no. It appears I'm getting desired performance. I'd probably have to run about three more times to confirm how difficult it is, but I would say desired performance requires moderate pilot compensation. We've got a minor but annoying deficiency. Primary workload is in the longitudinal axis, but I was having a problem in trying to maintain the precision — either accidentally or somehow getting into the yaw axis, and yawed it off. It increased my workload there, but primarily longitudinal, and the second area of work was in the roll axis. Pilot compensation increased to moderate level. You can call it an HQR 4.

Runs 224 and 225 (Slalom). Pilot decision: Is it controllable? The answer is yes. Is adequate performance attained with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I still have to say no here. We've got a deficiency that warrants improvement. It's a minor but annoying deficiency. Desired performance, I think, was attained. Moderate pilot

compensation in the task is pretty hard to find, and I'm not getting any longitudinal feedback so it really increases the workload to crosscheck for speed. The aircraft seems just a little sluggish in going through the course. It really increases the cross check so moderate pilot compensation is an HQR 4.

Configuration H (Fixed Base)

Run 226 (Hover). Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is still yes. Is it satisfactory without improvement? The answer is no. This is one of those where I think I'm working harder maintaining the desired performance so if you'll accept my one exception of the HQR Scale I'm going to have to give an HQR 4-1/2. Where I'm getting desired performance, but it's more than a minor annoyance, the workload is slightly elevated from a moderate pilot compensation. It's considerable pilot compensation required for desired performance, I'd give it a 4-1/2. Workload is up, but performance was there. I was able to attain the performance, but the workload is too high. There is no position for that in the HQR Scale. So I make it an HQR 4-1/2. Primary workload again was in pitch, but once I got into a little oscillation there in pitch and roll, and then crosscheck became very tedious to try to maintain altitude.

Run 227 (Vertical Translation). Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. I guess I maintained marginal desired performance throughout. It's a little hard to get on the altitudes. Almost got into a PIO. Did get in to a roll PIO. I guess I would have to say desired performance required more than moderate pilot compensation. Again, I think a 4-1/2 is an appropriate HQR. I got desired performance, but the workload was about more than moderate, and considerable pilot compensation. Mainly, I think I was working this time in the roll axis. I got into the PIO, and also a little bit of the heave here on the top. I guess I'd say I'm able to compensate in order to do the task to desired performance so to me it's Level 2 because I can do the task. Maybe that's the way I should state it.

Run 228 (Slalom). Is it controllable, the answer is yes. Is adequate performance attainable with tolerable pilot workload? No. We've got a deficiency that requires improvement. It's a major deficiency. Controllability was not a question, it was a question of workload. I think I was getting desired performance throughout, however, it required workload above a maximum tolerable. I give it an HQR 7, primarily due to the low predictability in the roll axis. I had to overcompensate on each one of the rollins and rollouts, and also on setting up to get on altitude getting into the slalom. I was having a problem in the heave axis. Airspeed and altitude seemed to be okay throughout the task. I think those were desired performance, but I didn't see any problems in those two axes.

Low-Bandwidth Rate Response-Type (Fixed Base)

Run 230 (Hover). Is it controllable? The answer is yes. Is adequate performance attained with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I guess the answer there for rate command is a yes. It had a fair, mildly unpleasant deficiency. Got desired performance throughout so minimum pilot compensation required for desired performance. It took an occasional 1/2 inch input every one or two seconds in both pitch and roll so it gives it an HQR 3. There were a little bit larger inputs, but not less frequent than required with the previous baseline.

Runs 231 and 232 (Vertical Translation). Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it

satisfactory without improvement? Basically yes. Again rate command so there is some workload associated with it, but it's mildly unpleasant deficiencies. A little extra work in pitch requiring probably 1/4 inch inputs very infrequently. Minimum pilot compensation required for desired performance, HQR 3. About the only real workload was in the pitch axis, and that was occasional inputs, pretty small. Would comment that it feels a little sloppy. It kind of wallows a little, but it stays right on the spot. It just kind of wallows around it.

Runs 233 and 234 (Pirouette). Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. The deficiency warrants improvement. Not necessarily aircraft characteristics even though the aircraft is sluggish, and that's a little objectionable, but adequate performance required considerable pilot compensation it's an HQR 5. It's probably an appropriate rating based on the performance. The aircraft is sluggish so when I start getting off, it takes multiple corrections to get it back on. It seems like most of the workload is in roll going to the right. Most of the workload is in pitch coming to the left for some reason. That's kind of odd, so that means you use a slightly different technique in both directions. Adequate performance was repeatable so HQR 5. It's odd that when I go to the left, I feel like I'm constantly kind of putting longitudinal pulses into the stick. When I'm going right I don't sense that at all. Attitude indicator looks like it's level, and I haven't noticed that before except that's what I perceive now. That may be just the way your hand reaches across your body to grab the stick. What I think it is, my arm has to reach across my body when I go to the left so I sense more activity in pitch. I'm reaching further because the stick is out to the left.

Runs 235 and 236 (Slalom). I don't know if it's the setup that makes it easier or what. That's probably the easiest slalom I've done. I think that was desired performance throughout. Pilot's decision: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. It was fair, some mildly unpleasant deficiencies. Minimum pilot compensation for desired performance, HQR 3. I got desired performance all the way, probably maybe plus or minus 5 feet on altitude. I gained a little bit of airspeed, and I lost right back down to the minimum throughout the task. Making the turns was easier. Turn coordinating with my feet was easy, so HQR 3. I really didn't find any major problems.

Runs 237 and 238 (Bobup/Down). Pilot's decision: Is it controllable? Yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I'd have to say no. We've got a deficiency that warrants an improvement. It's a minor but annoying deficiency in that I perceive a low heave damping which makes predictability in height control more difficult. It requires me to pump the collective a couple of times at both the top and the bottom of the bobup and bobdown in order to stabilize on the altitude. Desired performance required moderate pilot compensation, HQR 4.

Runs 239 and 240 (Dash/Quickstop). I find these interesting. Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? The answer here is yes. Again it's fair but mildly unpleasant deficiency, and it seemed like you get a little zoom climb here that I have to really milk through on the deceleration to get it to maintain altitude throughout the deceleration. I can't be quite as aggressive as I would like to be. It's just a matter of keeping a constant crosscheck, and moving the controls. Minimum pilot compensation required for desired performance, an HQR 3.

Runs 241-245 (Sidestep). Pilot's decision. Is it controllable? The answer is yes. Is adequate performance attained with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. We have a minor but annoying deficiency, primarily in roll, Desired performance required moderate pilot compensation. I had a hard time judging on the rollout, and predicting the time to begin the rollout to roll out on the desired position. I ended up when I thought I was going to enter a PIO, but I only got one oscillation. It wasn't really driven as a PIO so I was having a little roll oscillation, and predictability was low. Make it an HQR 4.

Baseline Configuration

Run 250 (Hover). Is it controllable? The answer is yes. Was adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? For rate command? Yes. It's fair, some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. I'd say probably HQR 3. The mild deficiencies are just some drift... actually, it's maintaining attitude, it causes some drift, and it just takes occasional small corrections to maintain position. Altitude was not a factor. Heading was not really a factor. Desired performance, but mainly XY corrections. That was HQR 3.

VCRs: I will mentally try to transpose my mind here, and I'm not thinking cues, I'm thinking controllability. Attitude control: Controlling attitude with the cues available, I would say probably a 2. That was between fair and good. I think I can tell where it went, and I could control it very precisely, especially since it seems like it's a rate command/attitude hold. Horizontal translational rates: Those were a little more difficult. That's where I had most of my compensation, I would say those were a 3. Vertical translational rate: I sense no correction requirement. Cross checking the altimeter, I had no requirements to make a correction, so ability to affect the translational rate is kind of hard to rate. I really can't rate that, I'm talking about my ability to by the definitions. When you read the definition it would say, "can make aggressive and precise corrections," where there are no corrections made. "Can make limited corrections" when there were no corrections made. "Only small and gentle corrections" when there were no corrections made. It's kind of hard to rate when you don't have a response to correct by the way it's written. I think that [no rating] actually makes the biggest sense because that axis was not active in the past.

Run 252 (Vertical Translation). Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? For this control system the answer is yes. I'm always biased there. There was some pilot compensation. Minimum pilot compensation required for desired performance. I'm assuming all those parameters were met, they appeared to be which would make it HQR 3. The minor mildly unpleasant deficiencies were primarily in depth perception, judging and maintaining this constant angle as you go up and down. It's a high gain task being in three axes of control. That's the main requirement here so that's HQR 3.

VCRs: Attitude Control: I would say here that limited corrections were confident, and precision was fair. I'd make it a 3 for attitude control. Horizontal translational rates: That's where I had the most difficulty. I found a little delay in my perception of translation, so that's where I would say between fair and poor. I'll go ahead and give it a 4 on translational rates. Vertical translational rate: As I began it was hard to perceive those rates, and what kind of control inputs were required. I picked up on the pirouette circle. It made that a little easier, so I started making a little more aggressive corrections, and there at the end I actually have to

give that a 3. Precision was only fair, but the corrections I could make with a little more confidence, so I give that a 3.

Run 253 (Pirouette). Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I would probably say no here. It's minor but annoying deficiencies, requires some moderate pilot compensation, which ends up an HQR 4. Primary compensation is judging drift, and it seems like it's slow in picking up the drift. It's a four-axis maneuver for the most part. The depth perception becomes a problem. I'm slow on picking up rates, therefore slow with corrections. I have to up my gain when I do see a correction, because it's already going towards the limit. Moderate pilot compensation to maintain desired performance so HQR 4.

For the VCRs: Control of attitude: Make corrections with confidence. Precision is only fair, primarily because the delayed perception of the drift. I'd have to give a fair, probably a 3 on the attitude control. Horizontal translational rates: That's where the major problem was, and it's not to the point where only small and gentle corrections were possible. Consistent precision is not attainable. Not that bad, but I'd have to give it a 4 for horizontal translational rate. Vertical translational rate: I did not go outside my boundaries, and I could see the climb and descent. The crosscheck was quite rapid. I was picking up on the translational rate changes and making corrections. Precision was fair. I'll give that a 3 for the vertical.

Run 255 (Slalom). Pilot's decision here: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I'd have to say no. There's a moderately objectionable deficiency here. Adequate performance requires considerable pilot compensation sounds more appropriate. HQR 5. Major pilot compensation is to complete the task, which is a high gain task between the poles, and monitor airspeed with the cues available. Picking up a loss of 10 knots airspeed is not easy, and it's not that perceivable. Even though I inched it up to almost 40 knots to begin the task, after the second turn I looked down, and I was at 31 knots without any feedback whatsoever that I lost the airspeed. I'd say that I got adequate performance with considerable pilot compensation both in and out trying to keep track of the speed. That's a 5.

The VCRs: The control of the attitude: As far as controlling the attitude here, I believe I'm getting aggressive, and I'm getting better than fair. The precision, in setting the attitude that I'm at least trying to command, I would have say that on this task the attitude is probably better than fair. I give it a 2. Control of horizontal translational rate is not as good, and I have some difficulty flying the model the way it's designed, so I'm not getting the precision that I would like. I'd say the horizontal translational rates are probably corrections with some confidence, precision is fair, maybe a 3-1/2, but slightly worse than that. 3-1/2 for horizontal translational rates. Vertical translational rate was not too big a problem. I was making corrections. Precision was kind of in and out, so I would have to say it's probably a 3 on the vertical translational rates. Precision was fair.

General comments on the task: While trying to crosscheck to maintain the distance from the poles, and make sure that I didn't hit them and I didn't go too far out, I would then crosscheck back to pick up the airspeed because I didn't have an adequate cue to change the airspeed. It made the task much more difficult, but I lost the airspeed without knowing it, so I was constantly trying to go in and out of the cockpit while trying to maintain a high-gain task. At these speeds I'm not sure that [airspeed control is] that important. It gets back to the design of the task. If I'm trying to do this kind of course [in the real world], I probably wouldn't be concerned about precise airspeed control.

I'd be more concerned about trying to get through the course in as fast a time as possible, or as precise a track as possible, or some other parameter. I don't believe airspeed control would be a primary consideration. [In flight] you'd have to glance down a lot for airspeed; it might be a little different, but you're going to have the same kind of problem at these speeds.

Run 256 (Bobup/Down). Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I guess I would have to say, yes. It's fair. Some mildly unpleasant deficiency that's very small, and the unpleasantness is primarily arresting the bob down. What I did perceive was the low damping. I'm not sure it's the washout of the motion that I'm following, or if there is low damping in the heave axis, because I seem to cycle the controls two or three times trying to maintain the same altitude. This is primarily only seen on the bobdown, probably due to the high sink rate. Some minimal pilot compensation required for desired performance. Make that HQR 3. I think I got desired performance three times in a row, in 11 seconds or less, so HQR 3 seems appropriate.

On the VCRs: Attitude control: Very few corrections here required, but I was in the axis with small precise corrections. I would say the result was probably between fair and good. I would have to give the attitude control a 2 in that I could be aggressive and precise. The precision was not as good as it could have been, but it was better than fair. Horizontal translational rate: There is some drift perceived, but I have very little cues for it. I have a problem in rating it, again, the same problem as before. I was making some minor corrections on what I was perceiving on limited cues, so I would have to say that I was getting corrections with some confidence, but precision was a little less than fair. Maybe a 3-1/2 would be appropriate at this point. Vertical translational rate: I think I was being quite aggressive with it. Precise corrections with confidence. Precision was not quite as good as I would like based on the comment I made earlier about the perceived low damping. I was making several corrections to maintain altitude. I'd have to give that a 3. Make it fair, because I was getting fair precision even though I was getting aggressive inputs, and precision is not quite as accurate as it ought to be.

Runs 257 and 258 (Dash/Quickstop). I used about 17 degrees nose down on the acceleration. Achieved 60 knots just prior to the decel point. I used 22 degrees nose up on the decel at the highest point, and maintained altitude within the tolerance, and heading within 5 degrees. So, is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I believe we got all the desired performance without that much pilot workload. It's a very high gain task in using all axes so I'd say that minimum pilot compensation is required for desired performance. It's fair, mildly unpleasant deficiency. Mainly the workload is continually monitoring the trends because there is a tendency to balloon on the deceleration. The rate of pitchup has to be monitored, not only through the climb, but the zoom effects also to end up at the designated deceleration point or stopping point. It's just minimum pilot compensation due to the fact it's a multi-axis task. Okay, HQR 3.

On the VCRs: Control of attitude, precise corrections with confidence? Yes. Precision is a little better than fair, but not that good so I would say my attitude control is not exactly the best in the world. I'd have to give it a 3. Precision was fair, it's beginning to get consistent with workload increase. Horizontal translational rates? That seems to be pretty consistent, ending up at the deceleration point, at the stop point so I would have to say, again, corrections with confidence. Precision? Precision is fair. It ended up being too high rates at the end so it may have been tied up to the attitude, but I'd have to again say it's a 3. For vertical translational rates, I think there's a little bit more difficulty in controlling that. It has to do with the cues. I would have to say,

corrections with confidence, yes, but precision is worse than fair. I'd have to give it a 4 on the vertical translation rates on this task.

Runs 259 and 260 (Sidestep). Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement I have to say no. We have minor but annoying deficiencies, and desired performance required moderate pilot compensation is an appropriate comment, HQR 4. Primary compensation is, I hate to use the word, but due to the restricted field of view. It's very hard to pick up the fore and aft drift because I can't look straight out to see my flight path line. Once it's perceived it's hard to determine whether to put a lateral, a longitudinal, or a yaw input in to correct it. On the arrestment on each end it's a high rate arrestment. I almost got into a heave PIO, and I end up in three or four lateral PIO's, oscillations I should say. It looks like a PIO to me off each end, and so it's primarily in roll, and in heave, even though I'm meeting desired performance all the way. Because of the multi-axis corrections, and I can't tell if it's biomechanical feeding in to the roll or if it's a visual illusion that's requiring the additional inputs. It's hard to say here, but I'd say it's an HQR 4.

Going in to the VCR: Control of attitude? Okay. Here are the same comments I just made for corrections. I'm having a harder time picking up on the longitudinal drift because of the limited field of view. My corrections, the question whether I can make it with confidence is extremely questionable. Attitude control, I know where the attitude is, so I can make those corrections quite good. I'd have to say that precision is fair. It's a 3 on attitude control. Horizontal translational rates is where the biggest problem is, and there the corrections can't be made with confidence, and precision is not as good as fair, so I give it a 4 in horizontal translational rates. Vertical translational rate? Control of vertical is also a problem on the arrestment as I described earlier. Precision is less than fair, but it is attainable. I met desired performance so I have to give you a 4 in the vertical translational rate.

Baseline Configuration (Modified Motion System)

Runs 261 and 262 (Hover). Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I'm going to have to say the answer is no. The aircraft characteristics are minor but annoying, and did require moderate compensation for desired performance. I believe I was getting desired performance, but the aircraft seemed like it was wallowing. Not much proprioceptive feedback so I'm picking up the drift primarily visually, so it made it much more difficult to hold position. I did lose the cone both times when I was doing it. I lost the cone right out of the corner just briefly. So I still show probably desired performance, but a lot harder workload, HQR 4.

VCRs for these: Control of attitude? Control of attitude was about the same as before, so corrections I think were made with confidence, but in precision control the attitude was fair, probably a 3. Horizontal translational rate? That's where I seem to have more difficulty perceiving it, correcting it, so corrections were a little less than confident. Precision was a little less than fair, but precision not attainable is not appropriate so I guess it would be 4-1/2 for horizontal translational rate because it was pretty poor, constantly in the axis. Vertical translational rate? Crosscheck revealed no corrections necessary, and I don't believe I made any collective inputs, so I have to say not rated.

Run 263 (Vertical Translation). It was controllable. Adequate performance attainable with a tolerable pilot workload? We got desired performance, and the answer is yes. Satisfactory without improvement? I guess I'd probably have to say no here. We've got a minor but annoying deficiency,

and primarily I'm feeling something in heave. I just slide up and down this little path here for the landing task. I'm occasionally getting what looks like a floating feeling in the wrong direction. It's very annoying, and I think that I would have to base it on aircraft characteristics. Not workload, necessarily, because I was getting desired performance. I call that an HQR 4 due to the annoying deficiency. I feel like I'm going down, and occasionally I feel like I've kind of blossomed over, or when I go up, I feel like I'm of out of sync somewhere in that translation. It just doesn't feel exactly right.

Now with the VCRs. Attitude-wise, I make aggressive and precise corrections with confidence, and precision is good. Attitude control is about the appropriate comment. There's not much corrections here. There shouldn't be any requirement for correction, but I had to make a few. I'll probably give it a 2 there on attitude. There's actually much that I'm doing in those axes, so what I'm doing seems to be pretty good. For horizontal translational rate? Due to the other tendencies, my focus is drawn away from that due to the vertical problems. Yes, I believe I was making limited corrections with confidence. Precision was probably a 3 in translational in this task. When it comes to vertical translational rate, I was having more difficulty, and I felt that I was only making small and gentle corrections. I'm still getting some precision so it's better than a 5 but not as good as a fair. I'd have to say probably a 4.

Configuration A (Low-Bandwidth Rate)

Run 265 (Hover). I'll start off with a brief description. The aircraft was just wallowing around. I was having a lot of problems in pitch and in roll, wallowing around, and I had a hard time controlling it with any precision. Maintained basic precision pretty well except twice the cone did slip right out of the corner of the window and went immediately back in. I'd say probably just getting adequate performance there from trying to keep it in, but considerable workload in order to do that. Is it controllable? The answer is yes. Adequate performance attained with tolerable pilot workload? The answer is yes. Satisfactory without improvement? I have to say no. Considerable pilot compensation would be an appropriate term here. We've got a moderately objectionable deficiency? It wallows around, and I had a hard time finding any precision control. It's probably marginal desired to adequate performance, HQR 5.

Run 266 (Vertical Translation). The initial thing is I had the same problem stabilizing in the hover before, and that was all consistent. As I got closer going to the 10 feet, the cues got stronger. I ended up almost getting into a PIO in both pitch and roll. As I moved away from it in a higher altitude it seemed to smooth out, and back to hover was fairly like at the beginning, requiring small, infrequent inputs. Was it controllable? The answer is yes. Was adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. I think we maintained desired performance throughout, but required moderate compensation probably an appropriate level. Desired performance with moderate compensation so we'd have to call here a minor but an annoying deficiency, as long as I didn't have to try to stabilize too long. An HQR 4. It seemed like the longer I tried to stabilize the higher the workload would get. It began to go up.

Runs 267 and 268 (Slalom). The first thing I noticed with any corrections on the run-in, I start getting into a pitch oscillation which appeared to be out of phase even at low frequency, which was where I was operating. As soon as I got into the maneuvers, even though I was maintaining airspeed fairly good, you still feel a negative sense in the vertical axis, which was a distraction throughout the

task. I found it very objectionable to the task. Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes as far as the performance goes. Is it satisfactory without improvement? I'd have to say no. Not necessarily based on workload, but aircraft characteristics are very objectionable. The oscillations here gave me negative sense, and I kept cross checking. The airspeed was fine, but I was getting cues that the heave was going the wrong way. Altitude looked alright so I call it a very objectionable aircraft characteristic which makes it an HQR 6 even though I probably had desired performance throughout the task. I consider the aircraft characteristics predominant so it'd be an HQR 6.

Run 269 (Bobup/Down). This confirms the last statement I made on the slalom course, what I perceived was probably in pitch because heave seemed so well behaved. Very strong initial cues, seemed in phase for the bobup and bobdown. I'm still getting a slight bobble at the top, and maybe more than slight bobble at the bottom. That's going even more aggressive than required. It appears to be still a little bit low damping, but that is all I can say, but we got desired performance, I believe, throughout. Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. For the limits of this task, is it satisfactory without improvement? I'd probably say yes. I don't think we overshot, and I don't think we did exceed the 12 seconds so I made desired performance throughout. The workload wasn't that high even though it's a high gain task. Minimum pilot compensation required for desired performance. Some mildly unpleasant deficiency mainly in lack of cues fore and aft. drift, and the perceived low heave damping. Make that HQR 3.

Run 270 (Dash/Quickstop). On the dash/quickstop, in moving up to stabilize the hover, it's the same thing as before. On the pitch down it seems like it's less precise in setting the attitude I wanted for the acceleration. I overshot it just a little. A little bobble. Also about half way through the acceleration, it seemed like I got in to a slight roll oscillation, but it was very minor. On the decel, I tried to drop the power and start the deceleration. The pitch rate I had a little trouble containing the altitude to stay within desired performance, and then it wasn't slowing down very fast. I ended up increasing the pitch attitude fairly high for the final deceleration to hit the desired stop point, and the pitchover at the end. In order to come to stable hover, it felt very uncomfortable. As far as the performance, it felt like it stayed within desired performance. Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? Probably no here. A little bit low predictability in the pitch, and then the sensation was a little odd — it's the only word I can use — on the pitchover at the end. It's minor but annoying deficiencies. Desired performance, I believe, was met, but required moderate pilot compensation. An HQR 4.

Pilot comment card: Is your flying technique modified because you are flying a simulator? Trying not to. That's about all I guess I can say. I'm trying to fly in a precision as you would in the aircraft, however, on the task that we did here I didn't have the field of view limitations. Kind of the ones you restricted me to so that really isn't a factor except in the overhead, on the bobup I have to anticipate the stop point, but that's about the only thing that's changed. Comment on response? This particular one was probably a little sluggish. It felt like it was coming from low sensitivity or low damping. Maybe a combination of both, I'm not sure, but when I move the controls it seemed like it took a slightly larger input, and the oscillations were kind of wallowing around. It was low on predictability or very low on crispness, and unusual characteristics. There was some kind of pitch bobble that I couldn't exactly pinpoint on a couple of the maneuvers, specifically in the precision hover, the landing task, and then it felt odd again at the final end of the deceleration. How did the motion cues affect your control of the aircraft? I had an odd sensation of this pitch oscillation in the

hover. I ended up trying to make smaller inputs, but ended up just kind of wallowing around, and I think part of that was due to the motion cues, I'm not sure. The motion cues for the most part did help me, except I wouldn't necessarily say they were realistic especially over on the pitch over the deceleration. For the most part, I guess they helped. That's really what we're trying to get out of this one. Okay, compare this motion system with the other systems flown in this experiment? This is probably worse than the others I've flown, I believe. The one I was flying before this one had some characteristics I didn't like, but they weren't as bad as this. Again, there's some things, I'm not sure whether this motion system or control system is a little worse. The motion and visual cues seem consistent. They pretty much seem consistent here, I guess, unlike the one I flew just the last period. If there were any unusual, conflicting, uncomfortable visual or motion cues please describe them and note which axis they occurred in? I think I described the slightly uncomfortable one, like a little oscillation in roll and pitch. The only conflicting motion cue I seemed to get was right at the end of the deceleration. I did the pitchover, and it felt odd. I'm not sure exactly what it was. It could have been just the pitch rate I was using. Was there any feeling of discomfort, nausea, disorientation or illness? The answer is no. Please discuss any obvious deficiencies in the visual scene? Primarily it's field of view, so that we can't see the ends of the bobup, and picking up rates. That's a slight problem.

Configuration A

Run 271 (Hover). I was able to keep the cone in the lower half, but it was wandering back and forth. Primarily, it kind of felt like a drift left and right. Every time I made a correction then I'd end up in the pitch axis to keep it from sliding aft on me, so I was working two-axis primarily. Heading was good. Altitude control was good. The only axes were longitudinal and lateral. Quite a few inputs, but maintained altitude, and heading was with in desired performance. Entering the table: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Satisfactory without improvement? I'd say no. For a hover there were too many corrections required, and some annoying residual motion felt. Not really amplified. but just there every time I made an input so it's a minor but annoying deficiency. Desired performance required moderate pilot compensation, and I think that's appropriate inputs both longitudinal and lateral. HQR 4.

Run 272 (Vertical Translation). The first thing I'll make a comment on is that the aircraft is still wallowing around. There's some residual motion. It's like there's too much motion for the small corrections I'm seeing when I went from 20 down to 10 feet. Because of the motion, I ended up making a couple of little stops. I arrested the descent a couple of times because it felt like I was sinking faster than the visual was showing me so I end up kind of stairstepping it down. The same kind of thing going up. I had a little trouble stabilizing at 30 feet because it felt like there was a residual motion even after I stopped inputs, and then back to 20 feet with the same kind of thing. Almost like I'm riding a little wave and it's a little discomforting. Entering the table. Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is still yes. It's uncomfortable, but it's tolerable. Is it satisfactory without improvement? I guess I'd have to say no. We've got a minor, but an annoying deficiency. Again it's the same kind of sensations I just described. I'm getting desired performance, but it's taking moderate pilot compensation to overcome a tendency to want to arrest my rates. I perceive the motion as being a higher rate than the residual. HQR 4.

Run 273 (Slalom). Initially, on the run-in, it's still like the aircraft is just kind of wallowing a little, like I'm on a wave. I think we kept the airspeed up. Altitude was within plus or minus about

5 feet throughout the task. The motion, again, seemed to be high. I hit the software limit, which is just devastating when you hit it. It's very uncomfortable there. The kind of situation you wouldn't want to fly with at all, so here, I would enter the table saying: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? I'd say no. That motion is intolerable, hitting the software limits. It's a major deficiency. Controllability not in question, so adequate performance not attainable with maximum tolerable pilot compensation. It sounds like a misnomer, and we're getting desired performance, but it's just not tolerable. The motion system here is not tolerable so actually it's the aircraft characteristic, I guess, that makes it a major deficiency. HQR 7.

Run 274 (Bobup/Down). When I'm trying to stabilize in the hover, it's wobbling just a little, but it's not distracting for this task. Just some minor corrections required to make it well within the time constraints, and the vertical height overshoots well into desired performance. So, running the table: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Satisfactory without improvement? For this given task I think I have to answer yes. I got a fair, some mildly unpleasant deficiencies in that it takes small corrections in the off-axis for stabilization, but minimum pilot compensation required for desired performance. HQR 3.

Run 275 (Sidestep). I'll initially start off again with the comment that the aircraft kind of wallows. A major lacking of precision in just trying to maintain a stabilized hover in the sidestep both right and left. When I start the input, I feel real subtle motion. On the arrestment, it seems like it's exaggerated, as if the input was delayed. This leads immediately into a PIO, while I hear the motion system really singing under me. PIO led probably to six to eight oscillations at least, and occasionally it even fed in to pitch. This caused great difficulty just trying to stabilize inputs or initiating the lateral to the left. It seemed like I drifted aft. too, and I don't know why the phenomenon occurred, but once it got corrected during the translation it was pretty comfortable. It was just the arrestment that was the major problem. Okay, entering the table. Is it controllable? Answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is no. It's a major deficiency which led to a severe PIO. Primarily lateral, but occasionally also in to pitch so that's a major deficiency. Controllability was not a question. That would make it an HQR 7. That's just an intolerable PIO.

[Comment card:] Is your flying technique modified because you're flying a simulator? For the most part, no. However, on this last task working the sidestep, again, I've got a restricted field of view. At the top of the bobup I had a restricted field of view also which does change characteristics some, but other than that no. Comment on the aircraft response, is it crisp, sluggish, any unusual characteristics? It didn't feel that crisp. Sluggish wasn't really slow like I would describe sluggish. It was more of a wallow, and it was very imprecise. How did the motion cues affect your control of the aircraft? It was of value for the initial inputs to start a motion, but then it seemed to be contributing to the PIO, especially on the lateral side step. Whatever motion effects were there it seemed to exaggerate the problem, and that had been the same thing I was feeling in the precision hover. It felt like it was exaggerating the problem even though I perceived it to be in vertical or pitch.. It may have actually been in the roll which is where the biggest problem showed up on the sidestep. Compare this motion system with the other systems flown in this experiment? This is probably getting close to the worst one I've flown. It's especially showing up in the lateral. Some of the others were much more precise, crisp and predictable. This one was lacking in most of those characteristics. Did the motion and visual cues seem consistent? There were times when they did not. It seemed like, especially in the landing task, that our sense of motion was perceived as being vertical motion, and not seeing anything in the visual except maybe a slight roll oscillation. It did not

appear to be consistent. I end up stairstepping down on that landing task because of that inconsistency. If there were any unusual, conflicting or uncomfortable visual or motion cues please describe them, and note which axis they occurred in. It felt like there was just a wallow or slight oscillation in that heave and/or pitch on the initial task. At the end of the sidestep, it appeared that the actual motion cue was lagging behind or was exaggerated, maybe like the gains were too high. The motion and all cues associated with that led to the PIO. It was a conflict with the visual, the aural, and the motion cues at that point which all contributed to the PIO. Was there any feeling of discomfort, nausea, disorientation or illness during the task? There was a little discomfort when I was getting what I perceived as motion cues in the landing task that didn't agree with the visual, but it wasn't very strong. On the arrestment of the sidestep, even though they were quite aggressive, it caused the discontinuities to seem larger. It was beginning to get a little uncomfortable on those sidestep arrestments. That's the only place it really occurred, and not to the point that I felt nauseous or anything. It was just kind of a knot in your stomach. Please discuss any obvious deficiencies in the visual scene. Deficiencies are obviously here with a lack of lateral field of view which I have already talked about, and a limited field of view vertically. It showed up in the bobup, and that part plus a little lack of texture to show subtle changes even though we got most of that artificially amplified with the objects in the scene.

Baseline Configuration (Modified Motion System)

Run 276 (Hover). Initially I'll make the comment that I still had a little bit of trouble stabilizing the hover. I had a little bit of wandering, it appears to be lateral, and also requiring a little bit of pitch to maintain precision position there. The cone slipped out of a corner there for a second or two. I'd say I'm probably making inputs about one input per second or so, and it's alternating back and forth between lateral and longitudinal to maintain desired performance. So, is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? It's a marginally acceptable there. It's fair with mildly unpleasant deficiency. It's mainly that it's wandering a little requiring small corrections, and I think minimum pilot compensation required for desired performance so HQR 3 for that particular task.

Runs 277 and 278 (Vertical Translation). Stabilizing the hover, it still wandered around, just a little, as I initiated the landing task. There appears to be some kind of uncommanded vertical motion that I end up arresting my descent a little early, and then wallowing in to a 10 foot height. On the way up, it felt like I was going across a couple of little waves in the motion. Up to 30 feet just a little pit pot stabilizing there. Several pumps on the collective, and then back down to 10 feet. There is some extreme motion that doesn't feel like commanded or some late followup or something. Entering the chart here: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I say, no. I think we had desired performance all the way around, but it's minor but annoying deficiencies, mainly in the motion response, and it's desired performance requires moderate pilot compensation, HQR 4.

Run 279 (Pirouette). During the practice I don't think that I was able to do this a single time without hitting the [motion] limit. I didn't perceive a limit even though I felt a couple of bumps in here. What I was doing, in order to compensate, to avoid the limits, was starting my deceleration early with small inputs. I was not making a sharp arrestment, and was taking an extra second or so on the deceleration. In that way I avoided the limits, but I still felt like I was always going across a washboard so something was just kind of opening that. That one may have been like the plus or minus vertical bump. It was very mild, just noticeable. What I ended up doing was just kind of

backing out of the loop to avoid the limits. With that in mind, and the chart: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. Due to the deficiency it warrants improvement, I guess I basically say that it is a minor but annoying deficiency at this point. By slowing down and just kind of backing out of the loops a little, I got desired performance, and it required just moderate pilot compensation mainly to make just the small inputs. If I made the larger inputs, and tried to arrest it rapidly, then I had a problem. It's an HQR 4 doing it that way.

Run 280 (Slalom). Basically, as I'm entering the slalom, and as I try to change the speed of entering the start gate here, there's something as I do the small pitch changes. I guess it's feeling that reversal, but very mild, and not too distracting. Once I entered the slalom course it seemed very easy to coordinate, and I didn't feel extraneous motion whatsoever. So in that case I'd say: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? In this case probably yes. There's still some pilot compensation in there on the speed control so it's fair, some mildly unpleasant deficiency, but minimal pilot compensation required and an HQR 3.

Runs 281 and 282 (Bobup/Down). I can initiate the standard bobup, vertical feels good. Very good onset, and feels right for the arrestment. I'm not getting any extraneous motion perceived at all at the top, or at the bottom. I'm probably doing a little slower arrestment than I had done previously, and I'm actually getting better performance, I believe, out of it. It's just a smoother application, probably more consistent than what would be in the airplane. I tried to get the technique back to what I'd do in the airplane. Going into the table: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? As perceived, at least for the task, the answer is yes. Minimum pilot compensation is required for what's perceived as just a limited field of view. There is still a little bit of low damping. It takes two or three collective inputs while I'm seeing very little external motion so I say it was a fair, mildly unpleasant deficiency HQR 3. I'm perceiving that I have to make two or three sine-type inputs to maintain position as everything dampens out at the top, so I feel I'm compensating for low damping with my inputs.

Run 283 (Dash/Quickstop). Initial comments: I'm getting a smooth acceleration. I was using at least 15 degrees nose down so that's about 20 degree pitch change to accelerate. Altitude control was real easy. It's a good cross check. Deceleration was nice and smooth, arriving at the desired point, and really felt nothing in there during the maneuver that was distracting. Just as I did the little pitchover, I felt a little motion, but it was high rate so I didn't really feel that it distracted from the task. On the table here: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? Yes. Just fair with one mild distraction right at the very end. Minimum pilot compensation required for desired performance, HQR 3. I complete the deceleration, and I push the nose down to the hover attitude, that's when I feel something. I guess the best way to describe what I'm feeling, is the pitch acceleration seems to be greater than justified by the input that I'm putting in. I'm feeling an exaggerated motion for the input just at that one spot.

Runs 284 and 285 (Sidestep). The initial comments: It appears it's smooth. I think I'm getting all the bank angles required, and aggressive levels at least as high as it should be on the first run. I'm getting to the right side, and as I decelerate into the hover, I'm feeling a negative motion cue. Some kind of bump that's quite strong right as I come to the hover, or just after I come to the hover. There's a tendency to drift aft as I accelerate back to the left correcting that. Got a fairly high rate

going over to the left, and the deceleration on the left side is almost in to a PIO. It's just that I'm getting very aggressive on that arrestment. It seems like I drift forward at that point, and that's pretty consistent every time. Once I'm stable, I move back towards the center, and try to get as aggressive in kind of a rapid reversal there, and it's a couple bobbles. They're not really driven into PIO motion but just some undesired motion there. With that in mind I'd call it: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? I think the answer is yes. Satisfactory without improvement? I have to say no. It appears I'm having trouble staying within the tolerance fore and aft. Drift, mainly, because with the field of view I can't really perceive the drift until I arrest, and I'm already outside the tolerance. I guess we've got a moderately objectionable deficiency, mainly the field of view, which restricts my ability to maintain the desired performance, Adequate performance required considerable pilot compensation, HQR 5.

Pilot Comment Card: Is your flying technique modified because of your flying simulator? I think I made the comment earlier that I was beginning to get into simulator syndrome. I had changed back to the way I would be flying an airplane, making smaller inputs on the bobup/bobdown. They were obviously way too large, stuff that I wouldn't be doing in the airplane, so I think now I'm back to flying it like I would fly the airplane. Comment on the aircraft response? It seems like it's pretty responsive, and crisp. The actual aircraft response is quite good, It's very easy to get the desired attitude from the controls. How did the motion cues affect your control of the aircraft? The motion overall is still quite valuable, however, there is a negative impact on some of these extraneous motions. The ones I had to avoid on the pirouette primarily, and the ones I felt during the deceleration on the sidestep. Those undesirable motions were really impacting and caused confusion in control strategy so those definitely affect in a negative way. Compare this motion system with other systems flown in this experiment. Obviously, I've already been aware that this is a system I flew before, and I have a tendency to hit some software limits which give me the negative motion cueing. It's probably not the worst I've flown, but probably the second worst I've flown in that regard. Definitely not the best. Did the motion and visual scenes seem consistent? I think I made several comments about those not being consistent. Primarily, I think the main comment I made was during the landing task where I got down to the low altitude. I was feeling some motion which did not agree. It was not consistent with the visual scene nor the control inputs at that point so there were some that were distracting. If there were any unusual, conflicting or uncomfortable visual or motion cues please describe them and note which axis they occurred in? Okay, I think I just described them. The axis gets confusing because what I perceive again is probably a vertical or a heave axis, but except maybe on the pirouette. The pirouette appeared to be always a roll axis. The motion that I was feeling during the landing task appeared to be in the heave axis, but it was confusing. The motion was like a wave or something. It wasn't easy to discern which axis it was in, but it caused problems in the heave axis at that point because that was the axis. Was there any feeling of discomfort, nausea, disorientation or illness during the task? I guess I really didn't feel that much. It was just a little bit uncomfortable every time I felt this extraneous motion. It didn't really affect me any except performance of the task. Please describe any obvious deficiencies in the visual scene? I think we've described them all before, but maybe the lacking of some cues on the lateral side step. We're obviously lacking in field of view in lateral. I didn't notice the line up for the accel/decel, but again because of the high visual content we're getting some strobing or flashing on and off, and some color changes. I'm sitting here watching the ring on the pirouette come in and out while I'm sitting here talking. Those are a little bit distracting but that kind of stuff for the most part goes away once we get out of IC.

Low-Bandwidth Rate System

Run 286 (Hover). Initial comments: Maintained the hover position. The craft just felt like it got twice as heavy. It's like I had a heavy aircraft under me, especially in the pitch axis. A little bit sluggish, low response, and kind of wallowing around a little so the inputs required are primarily in pitch but then small corrections required in roll as well. It kept me pretty busy. The workload wasn't all that high, but it felt like it was a much more sluggish aircraft to maintain desired performance. Okay, entering the table: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? Actually I'd prefer to see it improved here. It just wallows around, constant corrections. Primarily, I perceive it sluggish in pitch so I would say we've got a minor but annoying deficiency that required moderate compensation. HQR 4.

Run 287 (Vertical Translation). General comment is, in initiating any acceleration, I felt like it was going to be nice and smooth. I went down to 10 feet and then was constantly in the pitch axis. Probably plus and minus 3 or 4 degrees of pitch change, and it's really sluggish. It's like I'm just staying behind the aircraft, especially in pitch. A little bit of wobble in roll, but not too much. Due to the activity in pitch, I relaxed my crosscheck in the yaw. I realized I was going plus or minus about 5 degrees in yaw, so it was difficult to say within the performance standards there. Then I got off to 30 feet, and again it had several pitch oscillations. They become very annoying after a while trying to maintain the angle. Precision started deteriorating, and I had to kind of slow down to keep the task going, and about the same thing going down to 20 feet. There were several oscillations, and I think I actually went outside the heading constraints during the stabilization at 20 feet. At least I perceived it. It had several yaw kicks due to my inputs. I was trying to get it back to where it belonged. Entering the tables: Is it controllable? I say yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Satisfactory without improvement? The answer is no. Probably some moderately objectionable deficiencies for this task, and primarily the pitch bobble which led to distractions. I had to drop some crosscheck which led to dropping out of desired performance constraints. Adequate performance required considerable pilot compensation, I have to give it an HQR 5.

Run 288 (Pirouette). Initial comments: Going to the right, I did not see as much of the pitch oscillation as I'd seen during practice. There were still a couple of oscillations but they were very mild. Concentrating on keeping it a constant rate, I guess I got a little fast so the deceleration ended up with a three-axis oscillation. I tried to bring it to an arrest, and I felt like I was again riding up on a wave. Going to the left, I initiated it nice and smooth, and maintained an altitude and track. I then started getting small pitch oscillations about half way around. I maybe had three oscillations for half a circle. Then again, on the arrestment, even though I slowed down, it added another 5 seconds to the left, I still got into a 3 axis wallow as I tried to bring it to a hover. So I've gone to the table, I say: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? I perceived to stay with in the adequate performance all the time. Is it satisfactory without improvement? I'm going to have to say no. We've got a minor but annoying deficiency bringing it in to arrestment. It seems like there may be a question of control harmony. The pitch axis seemed so sluggish, and so slow. As I did this acceleration into the hover, I was in to all the axes it appeared. There was some question about harmony so I would say it's a mild but annoying deficiency. I think we had desired performance all the way so I'd call it an HQR 4.

Run 289 (Slalom). The initial comment is, I was straight and level running in to the slalom. Very low frequency pitch oscillation is noticeable as I tried to accelerate one or two knots as I went

into the first gate. It's observed, but not all that distracting. As you go through the first couple of gates, the tight turns there maintaining speed it looks like desired performance. You then pick up the aural cues from the motion system. They were very noticeable. It forced me to tighten my gains on the controls, and stay very tight with the visual feedback to keep from mistaking the aural cues as motion. I maintained desired performance throughout, but it's very distracting with the high whine of the gears when it was doing the sidestep. So, with that in mind: Is it controllable? The answer is yes. Is adequate performance attainable with a tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? I have to say no. We got desired performance, but we've got a minor but annoying deficiency. Primarily, a very strong aural cue to motion that does not agree with the scene. That alone is stressful enough to make an increase to moderate pilot compensation for desired performance, HQR 4.

Run 290 (Bobup/Down). Initial comments: Initial onset and the corrections felt correct all the way through the task. It felt very firm in phase. Since it's almost totally just heave, it felt completely correct. I'm entering the table: Is it controllable? The answer is yes. Is adequate performance attainable with tolerable pilot workload? The answer is yes. Is it satisfactory without improvement? The answer is yes. I really didn't see any problem. I've probably now learned to compensate for what I've perceived as the low damping. The high rates I was arresting, without even thinking about it, so I would have to say the pilot compensation really wasn't a factor here. I give it an HQR 2. It's good, negligible deficiencies. It's strange, but true.

Pilot Comments: Has your flying technique modified because you're flying a simulator? I don't believe so. I'm trying to fly it like the airplane. Comments on the aircraft response? Aircraft seemed very sluggish, especially in the longitudinal axis. In pitch axis it seemed like I was constantly in the axis. We had a little, maybe like low damping, in the pitch axis too because I was constantly making corrections on just about every task. I didn't really notice it in the bobup, but everywhere else I was in that axis. How did the motion cues affect your control of the aircraft? It seemed like they were quite good everywhere except on the slalom course. On the slalom course, due to the aural feed back from the lateral track, I was actually getting negative cues so that the aural cues were not corresponding with the motion and the visual. Again, a comment I think I made earlier just a couple of days ago, was that the soundtrack in here is very low. It's not drowning out the sounds of the motion cues like you probably desire. I'm getting a negative feedback there from the aural cues, otherwise it seemed pretty good. Same little turnaround bumps that I saw before, I'm still feeling some of those. Compare this motion system with other systems flown in this experiment? This one's kind of a middle of the road on them. On some tasks they're actually much better. Other tasks get a little worse so I would say it's just a kind of a middle of the road. It's got some deficiencies. Did the motion and visual cues seem consistent? The motion and the visual seemed quite good throughout. I didn't see any problems there. Primarily as I said before it was in the aural feedback from the motion cue. If there were any unusual, conflicting, or uncomfortable visual or motion cues describe them, and which axis? The only one that was really noticeable was the aural feedback from the lateral axis. Was there any feeling of discomfort? No. Please discuss any obvious deficiencies on the visuals. Nothing different than before.

E. PILOT T

Baseline Configuration

Run 613 (Hover). The only thing I see here, there's a little bit of oscillation in the X direction back and forth. Your VCRs are all slightly less than 1 — 1.5, that will give you an HQR of 3, and no unusual comments.

Run 614 (Vertical Translation). I find this to be sort of a 3-axis task. It's both longitudinal, lateral, and vertical. Aircraft seems to be pretty stable, you have no winds. What I find, also, is because you don't have any time restraint on the task, I could do this thing perfectly anytime. Given that I can hover the aircraft, I can definitely hover from 20 feet down to 10, and then back up to 30. It's just what kind of accuracy am I going to accept so, really, it's not the control system and the visuals that are cutting the accuracy on things, it's just my personal standards. Am I going to let the thing drift around a couple of feet, and say that's okay, or am I going to really try to hold her really exceptionally tight? Since I don't see the task being set up to be constrained to elicit real performance from me, I tend to be a little bit lax. I can fly the whole thing within your criteria and hardly work at it. Altitude easy to maintain plus or minus one foot. The vertical rates are okay since we've very little translation there to do. As you're looking down you have a tendency to translate a little bit because you're not looking out at the horizon. If you lose a little bit it's no different than normal hover. I think the cues out there are quite satisfactory. Going to the HQR Scale: It's certainly controllable. Tolerable pilot workload for sure. Satisfactory? Yes it is. Pilot compensation not a factor? No, that's not true so you don't get a 2. No pilot compensation required? Yes, that is true so you get a HQR of 3.

VCRs are 1.5 all the way across. There is some sense attitude-wise. You look down at the ground, you never have good attitude. What you really get is translational. Once you stop looking at the horizon or something largely out in front of you, I'm not sure I would describe the primary sense of motion as being attitude as much as translation. I don't have any sense of losing attitude either. VCR 1.5 for the horizontal translational rate. I would do the same thing if I was in the aircraft. I would have a hard time doing this sort of three dimensional task, getting it absolutely perfect both in the aircraft and here where I can practice it a little while. If that was the only objective for being here, I could probably get it so I could do it absolutely perfectly, and do it much faster. I'm not sure that's really the goal here. I see nothing wrong with the cues, and the task is easy to do so VCR 1.5 is fine. Vertical translational rate? Once again, I'm not getting any of the cues off the board for vertical for either the rates or the altitude. It all comes off this radar altimeter. If you really wanted to know what the cues were doing to you then you'd probably take this radar altimeter out of here. Given that you've given that for me to work with that's what I key on.

Run 615 (Pirouette). Time for the pirouette, 48 [seconds] on the first, 42 on the second. That kind of tells me that I can make it anything I want. I don't have enough practice to know exactly how to get it right on, and be totally efficient about it. The task can be flown in this condition quite well. I don't think it's a big deal to get desired performance out of it. Very little vertical drift. Obviously with 48 seconds, that extra 3 seconds helped. It does give you a little more opportunity to keep modulating your position fore and aft so it actually looks a little cleaner probably on the first one than on the second. I think all things considered it's desired performance. It's certainly controllable. Adequate performance with tolerable pilot workload? Of course. Satisfactory without improvement? I would say yes. I would give you HQR 3.

As far as the VCR's are concerned: Attitude. Are there sufficient attitude cues to give you aggressiveness? It's certainly aggressiveness within the character of the task. This is not a very aggressive task. Under ideal conditions you can zero in here. All you have to do is just set up lateral cyclic position, longitudinal and pedal position. If you got it just right this baby just goes around by itself. You don't really have to be all that aggressive. If you start screwing it up then you start seeing a requirement for aggressiveness. Precision seemed to be okay with me, certainly within your requirements. Let's make that a 1.5 rather than giving you a perfect score of 1. Horizontal translational rate? A good sense of that as far as the cues on the circle. The fact that you had straight segments, and the cues having small corners there, I've got a good sense of translational rate. No problem there both longitudinal and lateral. Lateral is a little bit better than longitudinal. Part of the problem was having the circle set up the way it is. It's kind of an interesting task to be able to keep yourself oriented so that you're seeing motion in the X direction.
Unfortunately, I think there's a threshold. There's some minimum displacement that you have to create before you actually notice the displacement. It's one of those things that I have to move probably 5 to 10 feet before I really sense a need for correction longitudinally. Okay, let's give that a 1.5. I've got no problems with that. Vertical translational rate? Once again, no real senses moving vertically. It gets stronger if I continue to look at the disk that's sitting on the pedestal in the center. I get real good cues from that as far as vertical drift. It seems like I can stay within a couple of feet as long as I'm paying attention to it. If I stop paying attention to it then all bets are off. I could probably see 5 feet without any problem. That's because I get bound up by all the other things trying to crosscheck around, and I just forget or stop looking for the top or bottom of the disk. I think the cues in general are quite satisfactory so at worst a 1.5 there.

Run 616 (Slalom). Okay. I see desired performance there, and I don't think we got more than a couple squares away. The speed varied from about 34 [knots] early on up to about 40 as a max excursion. Altitude, certainly I think plus or minus 5. One thing: You initiate altitude at 20 feet, and allow a person to go to 15. He's almost in the dirt before he goes down to your desired performance parameter. That was not a problem here so you got good desired performance with no question about that. The task is not at all challenging. This is a cakewalk task. Just a nice smooth task, at least for this set of flight controls, and no hurry having to set up a baseline. It's easy to fly. It's actually a very mild slalom here to stay within your parameters. I guess I don't have much to say beyond that. If you don't touch the collective the altitude stays pretty much right on. The hardest thing to fly is airspeed because you really do not have any sense of changing airspeed. If you don't have your eye glued on the airspeed indicator it's changing a couple of knots. It's certainly controllable. Tolerable pilot workload. Satisfactory without improvement? It certainly is. Pilot compensation not a factor for desired performance? I actually would say that's the case here. If it's set up correctly you could probably get a 2 out of this, no problem. I find that the aircraft gravitates more towards 40 knots. I can set it on 40 and it just glides itself right through these things so 2 is the rating here.

Let's see, how about VCRs? Can you make aggressive and precise corrections, is the precision good? Out here I would say no. Once you get close to the pylons where you actually have something to look at, I would say that your precision was good. I would give you no less than a 1-1/2. Horizontal translational rate cues? Up in the pylon area, the lateral is good. Horizontal is comfortable I would say, but if you asked me to answer the questions here, can I make aggressive corrections in translational rate, I would probably say no. All I do, because of having to look at the airspeed indicator, I'm going to put an input in, and it's going to slow down. All I'm going to do is watch the airspeed indicator, and see what I'm getting out of it, and then I'm going to modulate a little bit if I need to bob it up or down. It's not a matter of taking the cues from the data base. I

know where I'm at, I'm within your other constraints, but I'm not going to have at all precise control over airspeed. I'm not sure what else to say about it. Fair cues? Limited corrections with confidence and precision is only fair. Small or gentle corrections. It's not a matter how big a correction you make, it's the fact that there's just nothing there to make the precise changes with.
I don't know how to use the scale here because I don't find that the words help me out that much. I have to say in all honesty I would do the same thing in the aircraft even if I was doing this out on the parallel taxi way. You've got to give me a criteria that says that I have to be right on speed. I can't tell that any better when I'm doing this kind of a task out in the real world than I can here. Once I get stabilized on the speed before I get into the task I get some sense of continuity for speed. Once I get in the task, I look down and I find I'm four knots slow, I got there without knowing it. The only reason I know that I'm four knots slow is because I look back in at the indicator, and then I say, okay, here's a step input increase of power. I have no idea whether it's the right one or not. It's an iterative process, and it's the same process in the vehicle as it is out in the real world. I guess I don't want to say that the cues here are preventing me from doing something that I would normally do outside the real world. I would be no better at it there than I am here so if we send the keys out there in a totally VMC condition, then if they're a 1 there they're no worse here, and it's the same process in the vehicle as it is in the real world. I can tell you that what I see out there is no better or no worse [than the real world], or put it this way, my ability to change the airspeed or to guess how it is changed from my prior 35 is no better or no worse here than it would be in the real world. Even if the cues are really good out there, this task without the constraints on it is just the way the task is described. If I tried to change my airspeed, or tried to gauge whether it's changing, I'm really hard pressed to do that in this kind of task. I've done a lot of these things, and I really don't know until I look back inside the cockpit what my airspeed really is. I can be fooled grossly, I could lose 10 knots in one of these things, and think that I'm just doing real peachy. That's a surprise thing in the real world, so it's not a surprise to me here that I can be off say 3 or 4 knots. That's about the way things go. Unless I really do a real good crosscheck between outside, inside, outside, inside, I will not be very precise. What I'm actually saying is this is one situation where I find the verbiage doesn't help me in describing what's happening out there. I feel that I don't relay to you an accurate sense of what I'm using to fly the task with using your descriptors. I just want you to know I'm not complaining, that's my assessment of it. I'm not thinking that you need to do something about it immediately. I just feel obligated to try to describe what I see as I'm doing this. For the record, translational rate, that is a 1.5. Horizontal translational rate is the one that would be hard to describe. Leave that as a line blank there.

<u>Run 617 (Bobup/Down).</u> I see desired performance on all counts. All done within 12 seconds. I think we actually got it without any great amount of overshoot on any one of the three. When we got it back to the bottom, I think we oscillated around 15 feet but we never go more than 10 or 20 so I think you get desired performance. The task is actually easily done, and I find the operable technique is to put a big hawking bunch of collective in to get it started, and then as you start going up in altitude you start taking it out so that you're actually slowing down so when the targets start coming in to view then you're not just flying straight through them. That's a problem in this simulation where you can't see the targets all the time. You have no way of getting any lead on them until they come in to view so you've got to start taking the collective out. I'm doing that and I can still make the time period, and I seem to be able to slow down very nicely on to the targets. Bringing it back to the ground, I think I have a good sense where 15 feet is. The vertical axis of control and response to the vehicle seems to be very nicely tailored so I think you get actually very nice response out of the vehicle. It's a little bit lagging in ways, but it's predictable. I can do this task within recognizable and acceptable bounds. So it's certainly controllable. Adequate pilot workload certainly. Satisfactory without improvement? I've got nothing to complain about. So it's

satisfactory. Pilot compensation not a factor for desired performance. There's no pilot compensation required. Actually this is one of those where all of the estimation, and all of the compensation comes in to estimating the slowdown to come up on target. This one takes all the energy. The rest of it is actually open loop with the possible exception of the bottom where my sense of altitude is well supported by the checker board. There's no sense of driving it through the ground at any time. Of course, you get the feedback from the radar altimeter that tells you you're right on so don't mess with it. Just bump it and come to a stop. There's a little bit of float there, but we're floating around within the desired range so I had no problem with that. Why don't you say if a pilot doesn't have to compensate for it let's make it a 3 and see if there's some minimal amount of compensation required.

VCRs. Can you make aggressive and precise X corrections in attitude? It don't seem to be required here, but I have a sense that I could do it, I seem to be able to maintain myself pretty much in the ballpark of the initial condition. In terms of XY I feel comfortable with it. I don't have any sense of being behind the aircraft. I have to say, of course, it's no different in the real aircraft than it is here. Once you get around the targets you lose that close sense of where the ramp is. Even in the real aircraft it's reasonably hard to bobup and stay right over the same spot. You have a tendency to translate. It's just something that's geometrical perceptive that causes you to translate off of that point until you figure out how to reverse compensate for it, then you learn how to do it so you go straight up and down. At this stage of practice while we're doing the real task it would be no different in the real world. I guess I end up giving you 1-1/2 gain for the attitude. Horizontal translational rates? Once again, I felt comfortable with them, a 1-1/2. Vertical translational rates? I think that works out nicely. I'd Like to say that the climb is clearly an open loop sort of thing until you actually get your first glimpse of the target. You've already started to take some power out of the move. All of a sudden, boom, you can close on it, and make one or two last corrections. It seems to work out okay so I feel that there's a good sense of cueing, and a good response from the vehicle that allows you to make aggressive and precise directions with confidence. Here's a real good place where you can look at the other side of the coin. When we did the slalom, I didn't find that the good X cues sentence was a very good descriptor for that task. In this task that sentence is just perfect towards this. You can make aggressive and precise X corrections with confidence, precision is good. I can see that directly in the task. Here's the point where that's excellent. I've already shown that maybe it's not so good in other tasks.

Run 618 (Dash/Quickstop). Once again a pretty simple task, at least in turns of getting it set up. Acceleration is good. I knew that I was sinking, but I don't know how much. Actually, I'm kind of surprised at times when I sort of put the nose down, the ground comes up at me a little bit. I have a tendency to overreact, thinking that I'm falling a little bit farther than I am. I find a small difficulty in trying to modulate the power lever to get the kind of response I want out of it. In a real aircraft with a lot of motion sense, somehow, those collective requirements come through much more clearly. You do it by second nature. You feel the vertical accelerations. You seem to able to sort out so you can sort of keep those inertially centered as opposed to aircraft body centered. It's a lot easier to do accel/decels in the aircraft. I sort of fall out of it, and I'm guessing as to what to do with the collective. You're down to the 60 knot point, and that went pretty well. It actually stayed still within the plus or minus 5 feet. Going in to deceleration, I really don't know what to do with the power lever. I know it's going to go down so I just push power lever down, and take it to where I think is a good estimate. I have to go back to the altimeter, and start using that as the feedback device because I really can't take it out of the data base. I don't really know how low I am until I've already screwed up. I started 25 feet, but by the time I get down to 15 feet I know that I've done something wrong, but then it's too late. I've already made the error. To prevent that, I have to keep going

back to the radar altitude to make sure that I've got it right or to get some trend information. I can see basic trends in the scene, but I don't get a threshold feeling until I'm already outside of your desired parameters. Okay, so how does it all work out HQR-wise? Certainly controllable. Adequate performance with a tolerable pilot workload? Yes. Satisfactory without improvement? Okay, this is one of those things that will be difficult to come up with because I feel like the actual response of the vehicle is fairly predictable. When you get down to the far end of this thing, the deceleration, I have a hard time modulating the power lever satisfactorily to give you a nice level deceleration; instead, I start hunting with it. I think you're still getting desired performance, but in this case the workload goes up a little bit. I think it's a little bit more than saying minimal pilot compensation. You can either get it just right with luck, or you can be slightly off, and start pumping the power lever, and you actually make it worse. It's kind of hard for me to think that would be a 3, so I'll give you moderate pilot compensation. The rating is a 4.

VCRs: As far as the attitude is concerned, I find that's pretty much the attitude indicator task here. Once you put your nose down, if you really want 10 degrees nose down then 15 degrees tilt so the perspective of the visual scene changes quite a bit. I am actually cheating on you a little bit. I put over the ten, and I take it back out. I can go back to five or six, something like that because I don't want to be looking straight down to the ground or what it looks like straight down. I actually cheat a little bit, knowing that the aircraft will accelerate up to 60 by the time I get to a point where I have to decel. I never really have a good sense of attitude when I put my nose down like that because I really can't see the horizon around. If I were in a real aircraft I think I'd have more peripheral cues. It would give me a grander sense of what the altitude is, or at least whether it's acceptable or not. How precisely can you control it? With the easy attitude indicator, I can also look at the texture here, that's the blocks, and I can get a precise sense of attitude change. It's not hard to see what's happening. The question is whether it's the right thing or not. I don't have a good sense of estimation. In the real world I take one good look at it, and I'd know exactly how much power or how much cyclic to change to get where I want to go. Here, it's a guess. On the one hand, you make changes aggressively with confidence. I guess actually your attitude changes can be done precisely. It's just that you don't know what they're doing for you. Okay, so I give a 1-1/2 for that. Horizonal translational rate. longitudinally, once again I can't tell 60 knots here. My sense of speed is really bad. My sense of speed comes off the airspeed indicator. When it says 60 I'm there. When I go into the decel, I have even worse sense of speed. I have a very poor perceptive. I look down there, and I don't see the two lines that are traversed to my line of travel. It's just a big grey area down there. As they start slowly down more, and more, then the stuff starts to fill in, but initially you don't have a very good sense of deceleration. You know the nose is up, you know you're slowing down, but there's no cues coming, there's no rush that's telling you about how it's operating. With no seat-of-pants cues, you really are just sort of floating ballistically which is one of the reasons that makes it more difficult to maintain level flight. Can't make limited X directions with confidence. Precision is only fair. I think this is one of those times when I go down to a 3 for the horizontal translational rate and that's in the longitudinal direction. I don't seem to have any problem with lateral. It's not a perfectly straight line, but then again I'm not putting a lot of attention on that. I know that if I just point the aircraft generally ahead of me that will work out. It's not a big deal. I give it a 3 here for the longitudinal. Vertical translational rate? We really sort of talked that to death. I could make limited X corrections with confidence. The precision is only fair. It's probably a fair descriptor, I'd like to be more precise, but I think I'll give you a 3 simply because I don't know out to break it down any more tightly than that. That's end of comments.

Run 619 (Sidestep) This is actually one of the more complicated tasks, I think, to do it well. Part of that is just the way the cockpit is set up. You can't look directly out to the side. Altitude

was good. The first run to the right probably did not fit your criteria. The bank angle was only about 10 degrees to start, and then I got a little bit concerned about that. I took it out early, and it only took about 10 degrees to recover so it's just sort of a wishy washy maneuver to the right. Flight from right to left worked out much better. I certainly met the criteria for aggressiveness. A bit of bobbling on the end, but generally pretty stable, and back to the center, and stop in good shape. I think the altitude stayed in good shape. I think the fore/aft direction looked the best of any events so far as I perceived it. The yellow line and the red/green stripe actually went through the instrument panel for most of the run so that looked pretty comfortable to me. Heading, I don't think there were any great excursions there. I don't think it was over 10 degrees. My perception is that the performance was desired. Controllable. Adequate. Satisfactory? I guess I have to say yes. It seems that I do the task exceptionally well. I think because of the estimation requirements on the end, and that business of being able to take the side flair, and drive it where you want it You actually have to fly past the point where you want to be, and as the aircraft swings back in you swing back to the point where you actually want the aircraft to be. All that requires, at least, minimum pilot compensation for desired performance. You get a rating of 3.

The comments on the VCRS. It's certainly adequate changes in roll attitude. I don't feel uncomfortable about that at all. I do have to go back to the attitude indicator because I'm trying to key on what you want me to use as a minimum. I do go back to the attitude indicator, but actually given more vision to the side, I can be far more aggressive with this task, and probably do it right on. Certainly in the aircraft. Here it's little bit more difficult. What are the cues? I think we could make aggressive precise directions with confidence. Precision is good in terms of attitude and horizontal translational rates. Longitudinal worked out quite well this time. Laterally, I actually think I did good. I never feel like giving you a 1.0 on these things because there's always something that actually is a little bit worse than the real world. Here, you lack sort of a sense of perspective for how far things are away from you. When I get up to the end of the lines, the end of the checkerboard, I have a hard time getting those just right. The sense of rate is okay. The problem, I think, is getting enough practice with it to know just how much control is required to smoothly take it out, and just swing back once, and be right on the point. Makes me think that I will give you a 2 for the horizontal translational rate, and that's in the lateral direction. Okay, vertical translational rate? That seemed to work out quite well. A little bit of sense of sort of sinking through there, but you pick up your cue quickly. That takes very little power once you set up power for the initial translational. It seems like when you start to roll level, you can take that much out, and you seem to be able to have enough power to sort of side flair, and come back to the point. Both the sense of vertical rates, and the ability to control the vehicle seem to be good so I'll give you a 1.5 for that.

Comments for the pilot comment card: First question is: Modification of pilot technique as a function of flying in a simulator? I think there definitely is some difference. I think overall I don't tend to be as aggressive with the aircraft. I tend to want to stop a little bit short of testing the attitude of the aircraft. Let's just play the game. You tell me what you want, and I'll try to find the proper sequence of controls to give the highest score. In the real world, I'd actually be pressing the issue a little bit more in each one of these tasks rather than trying to play it safe here. Use just enough control to get the job done without trying to push it. Aircraft response appears sluggish. Any unusual characteristics? I actually find the baseline model seems to be a pretty reasonable aircraft. Of all the axes, I'm probably most impressed by the collective axis, the fact that we could do the bobup, and actually maintain pretty nice control over the vehicle. It looks like it's fairly well shaped. A little bit sluggish, but I guess it's one of those things where my sensitivity would rather be a little bit sluggish than to have a virtually uncontrollable system. One that's either too juicy or so sluggish that it's just lethargic, this is kind of middle of the road. For a simulator, I think it's

satisfactory. If I were actually flying the aircraft, I'd probably want something that's a little juicier. How did the motion cues affect your control of the aircraft? I'm finding the actual motion cues to be fairly weak here. Obviously we don't get any thing out of longitudinal. Lateral cues are a little bit better. I don't think they come close to the real world cues. Particularly for things like the lateral sidestep here where you cruise around about 15 knots. Here comes the edge of the checkerboard, and boom — you wrap it up, and you do a couple of oscillations to sort it out in the line. That gives you a real sense of response from the aircraft. Here, what I get instead of a sense of the motion base trying to sort something out, I find that I get out of phase with the motion. I know where the CG of the aircraft is. I know where the aircraft is under my rear end. Here, I actually get out of phase a little bit, and I can feel the motion base working, and what I'm really trying to do is disregard it. I try to do it visually. Okay, if that's where the visual point is let me try to get over it. Once I slow down the inputs, everything will come together, and catch up with itself. So, in some way, I don't in any case like that, put much credence in the motion base. I sort it out as being something that I pay no attention to, until it starts to slow down a bit. Then I'll see if it matches up with what I see out there. Motion cues for something like the slalom task. They were quite nice. I find that those kinds of pitch, roll, and yaw responses are actually quite nice. I find the slalom is very nice to fly. I find the pirouette is nice to fly. Bobup is a pretty reasonable task. The accel/decel, I don't get as much out of it as you would expect. No comparison with other experiments since this is baseline. Motion and visual cues seem to be pretty consistent today. So far nothing is particular conflicting or uncomfortable. No nausea. The only discrepancy in the visual scene I would come up with would be the fact that you just don't have enough field of view to be able to see things, like when you put your nose down in the accel you can't see the finish line. You also can't look up. Likewise with a bobup, when you're coming up towards the target you can't bend down and look up into the CRT. Nothing is there so you end up just having to sit here and twiddle your thumbs. You're sort of in hold. You're just playing the game until some cue comes in that you can use. You find out that is kind of a deficiency, but once again, you are looking at the values of the simulator, and not trying to compare exactly to the real world. The other thing would be at the end of the accel/decel where when you really need to have a little bit more of a feedback of the things that you know to be down at the end of the yellow stripe. It'd be kind of nice to look down there and sort of see them at perceptive scale. My experience today seems to be that I'm slowing down a little bit too early, but I play the game, and I just want to try to do is not take the input out. Once I've got the input in there, and it looks like it's going to slow down, but not as aggressively as I would like, I just ride with it rather than try to mess with it because I know that it will coast in there, come to a stop short of the line, and I will stop seeing the pylons. On some level, I'm sort of on autopilot. I'm taking a wild guess at it. Well, I know this will be just about right. I'm not doing it from the cueing. It'd be nice to have those cues to look at, but it would be kind of hard to generate them though.

Baseline Configuration (Modified Motion)

Run 620 (Hover). The task goes quite well, and the travel over to the cones is done smoothly. I don't see any problems with control. The most difficult thing about the task is getting it set up so that you're exactly on 20 feet where the radar altimeter says you have plus or minus two to work with.. Once again we're seeing the indication here, plus or minus 1 foot. That makes it a little bit more difficult. I find that just a good crosscheck between the cones, checkerboard in front for lateral alignment, using one of the lines between the squares, and a quick check back for the radar altitude, and you can maintain a very precise hover with no problems at all. I don't see any motion cueing problems. I can sense that something is happening there. I have roughly the same feeling I did the last time I flew this that there's a slight, very subtle increase in the value of the motion system. There's something about it that is just a little bit better for me I think. I can't tell you. I can't put

my finger on what it is, but it just looks like the task gets done in a way that it gives you more acceptable feedback. Something about your judgment of the goodness of it is more comfortable. It's either the feel on the seat of the pants or the correlation between motion and the eye, it's hard to tell. I can't put my finger on it, but it seems to work out quite well. As far as the rating is concerned: Certainly very controllable. Tolerable pilot workload. Satisfactory it is. I'll give you a 2 for this. Pilot compensation required to get desired performance? As soon as you would stabilize the hover, you have to put some effort in to figuring out where you're at, and you tend to modulate the controls. The control inputs are so small that it's like no work, and it's not a high mental workload to try to calculate exactly what it takes. There's no feverish darting around the controls to maintain a good hover so I think that 2 is certainly a good rating.

Now, the VCRs: Aggressive and precise corrections with confidence and precision is good? Once again, there's not that much aggression involved in this task. The precision certainly was good, I had no hesitation to be assertive with the controls, but that just wasn't necessary so I give you a 1 for that. Horizontal translational rate? It seem to be quite acceptable. The transfer over to the cones as well as just the movement locally around the cones gives a good sense of motion, and it seems to be a good reasonable ability to zero out any translational rates that I can see, so I give that also a 1. Vertical translational rate, the same comments as last time. I'm not using the visual picture for vertical positioning. I'm using the radar altimeter, and in that respect I find that I have pretty good control of the vertical axis within plus or minus one foot. I have good resolution of the vertical controller, and there's certainly no problem in maintaining it. I guess you get 1's straight across there. I'm not sure what to say about the fact that the 1's are like a half a rating better than the 1.5's I gave you the other day, but I think in spite of the fact that's it hard to break out the differences, I think I'll let them stand as these seem slightly better. I do perceive an improvement, however slight.

<u>Run 621 (Landing).</u> The execution of the task is the same as last time. I don't know whether it's the motion system combined with the visuals or whatever subtlety might be there, but I find that I have a little better control down close to the cones. I also find that I'm trying to do the task a little bit more slowly. It's really made it an opened end task as far as precision is concerned by not putting any time constraints on it. If the idea really is to drive down the imagined glide slope between your eye ball and that cone, it's not all that hard to do especially if you've taking your time, and trying to be real precise with it. Once again the task is a little bit different than the landing task could be. It truly is a three dimensional task instead of a slightly different level than a normal climbing descend would be. It's done exceptionally well. I think the altitudes are right on. The precision in the window was certainly satisfactory. No high workload involved. No high control rates. It seems to be a nice, very well controlled task as I see it. As far as the rating is concerned: It's controllable. Acceptable pilot workload. Certainly satisfactory. Pilot compensation a factor for desired performance? I would not say that's the case here. Minimal pilot compensation required. The highest workload effort here is not in vertical control, you're using your radar altimeter for that, but in judging how much roll and aft stick you need to be able to compensate for the changing perceptive of the cones as you climb in altitude. That's where the workload comes in so there's a 3 for that.

Now the VCR's: Attitude is good. Do a 1 there. Horizontal translational rate, a 1.5 for that. Vertical translational rate is the same so I guess we'll end up giving you a 1 for that. It's kind of a strange thing, I have to say that I have a sense of rate when I'm looking down at the cones, and not looking into the cockpit. I sense what the speed was doing, but I have no sense of measurement. If you asked me to guess what the altitude would be I couldn't tell you, but I do have what I think is an acceptable sense of the change, the changing state of the aircraft. I just could not tell you how well it matches with some pre-imposed standard that I'm supposed to meet. As far as the cueing is

concerned I think it's actually pretty good. So, let's make that a 1.5 instead of a one for the vertical translational rate.

Runs 622 and 623 (Pirouette). All sense of control seems to be pretty appropriate given that lateral rate is set up. They're easy to accomplish, and they seem to be fairly easy to maintain consistency in lateral rates which I find good for this. Also, the heading wanders around a little bit, but rather than oscillate back and forth it tends to diverge at some point, drop some point, and that's purely a function of how much attention you put on it. I find that just a little bit of rudder pedal input at start gets it pretty well set up, and it stays there through most of the run. Timing is purely a function of how much you want to rush it. I think I could probably take a few seconds off it, and still do it okay. There really isn't much to practice. You could do this thing with no practice on it. You could probably do it in 35 seconds, and have no problems with it. We were able to do it in 45 seconds. As far as the rating is concerned: It certainly is controllable. Tolerable pilot workload? Satisfactory it is. I guess I end up giving you a 3. It's fair. The problem here is between fair, and some mildly unpleasant deficiencies. I don't really see any unpleasant deficiencies, but I do find that it takes a certain amount pilot compensation to be able to make it all work. The test thing is to draw the line between what's compensation, and what would be a normal workload. Actually, if you don't mind splitting it let's make it a 2-1/2.

VCR's: Attitude is 1. Horizontal translational rates, make that 1-1/2. The trick is to be able to stay right on the line. There's a lot of things wrapped up in how easily that gets done. Part of it is the field of view you have. Part of it is your orientation of the circle. Part of it is the fact that you have stayed within lines. There's a whole bunch of things that factor in to that, but just generally, I think they're pretty good so a 1-1/2 there. Vertical translational rate, I didn't really sense much of a rate. The vehicle is pretty stable. It has reasonable damping quickly so it stays where you put it without a whole lot of extra effort. It's almost like you're not putting in much effort in controlling it. Aggression is certainly not appropriate here; however, precision is a good word. Precision is quite good so I think I would end up giving you probably a 1-1/2 for that. The reason for the 1/2, it's not perfect. You still end up getting a lot of your cues from some secondary mode. I think looking out at the cylinder that's in front of you on the pole there, it's almost a radar altimeter. It's not what you would consider a normal attitude cue. It truly is a direct feedback of altitude so I think that's the thing that makes the altitude easy to handle. If it weren't for that, and the radar altimeter, I think that you would find people sliding off of altitude more easily.

Run 624 (Slalom). This is the first task where I think I see a negative difference in the motion system. Everything else has been very smooth. I found in the practice runs that this particular run made sort of a ratchety motion as you're making your course from the straightaway. You feel nothing, but as you start making your turns, I feel it's the motion base combined with the visual. I feel a little steppiness, and I feel a little bit of hesitation in that motion base. I know that in one of the slalom runs, I did hit a lateral stop when I really was not aggressively handling the aircraft, but simply just pushing it through the pylons. There's just something about it that's less smooth than the other tasks have been. Of course, it certainly was at a higher speed too. I don't know what to say about it other than I'm sensing something that is different. It is not quite as good as it has been. I'm too far gone from the last motion configuration to tell you whether it's really different from that configuration or any worse. The best I can do is just bring it up. Let's see: Airspeed control, 35 knots through most of it, I might have hit 34 at one point, then the last couple of pylons I get up to 40. I guess that's satisfactory. Altitude is very easy to maintain. That's not a problem. It's great cueing on the side of the pylons. One doesn't have to worry about that. Rating: Is it controllable? It is. Tolerable pilot workload? It is. Satisfactory? It is. I'd probably give you a 3. The workload here, minimal

pilot compensation is in airspeed control. I still find it kind of hard to get any sense in changing my airspeed as a function of attitude. If you asked me to jerk the aircraft around, I could tell you that I get real good cueing about the attitudes that I'm getting out of it while I'm trying to be aggressive. It's real hard to feel that you're getting precision, and I don't really have much of a sense of airspeed control here. I find that I get 35 to 40 knots without really thinking about getting any speed up.

VCR's: Attitude? On a large scale level I say it's good; but, when trying to get down to small enough judgments in attitude to make predictable changes in airspeed, that I can't pick out. I'm not quite sure how to use your chart, but let's try to put a perspective in. I think on this task, it's better to give you a rating of 3 because what we're really doing is using your scale for this task for those things which are important. I think airspeed is important even more so than just gross overall attitude in the large scale. You get a 3 there for attitude. Horizontal translational rates? Once again, I don't have a sense for making precise corrections. It's more of, lean on the control slightly, put a little pressure on it, and see what happens. To some degree, that's what you do in the aircraft as well. Here I don't get the same sense of feedback so I don't know when to take it out. I see 40 knots here. To be honest, I don't know what to do with it. I don't know whether to breathe on the stick, and try to pull aft a little bit, or just wait. The control technique is don't mess with it. Don't try to get in the loop because you'll probably screw it up. If you'll take that as a reasonable description of how it's done then you probably end up with cues that make limited X directions with confidence, and precision is only fair. Actually, I think that's a little too damning so let's strike an average between good and fair and make it a rating of 2 for the horizontal translational rate. Vertical translational rate? Once again, I don't have much of a sense of it based on the checkerboard, but I get a real good sense of vertical displacement based on the striping on the pylons. In that case, I think you have to say for the vertical translational rates the cueing is good, and the control is pretty decent. I don't have any problems sensing an ability to drive myself up and down the bands as I go from one pylon to the next. I'll give you a rating of 1 for the vertical translational rate.

Run 625 (Bobup/Down). A lot of your description of your performance depends a lot on how you do the task. It's actually kind of broad in some very significant areas. First of all, I don't see any power indication in here so probably on some level you're looking at an aircraft with an idealized torque limiting system. Otherwise, you can just pull max out of it. I never really know what I'm doing in terms of power, rotor rpm. If I get it estimated just right I come right out on the point, and I could just bring the collective to a stable point, the aircraft is stable, and boom — right back down. That's really perfect. The rest of the time, I find that I overshoot by a little bit about 25% of the time. The other 25% of the time, I get up there, I think I've got it stabilized, and I see myself drifting off, and take another second and a half to bring it back into limits, and then zip back down. In some ways it's kind of a flake task in terms of 12 seconds because I can shave a second here or there. If I really want to be precise with it I can play a couple of extra half seconds or full seconds in getting it just right, and I go over the limit. There's a lot of judgement involved on how you look at the ratings. Generally the task is done quite well. It's really a good vertical control, XY position of the aircraft although not perfect. It seems to be pretty well controlled considering that I'm not putting a lot of effort in to the aircraft. I have a sense of the aircraft staying pretty much in the same place. When you see a certain sight out there you know that you're right about 15 feet, and it's real easy to pull the collective back in, and you oscillate plus or minus 3 feet. The sense of it is real good. What I find surprising is that the timing is considerably better this time than on Configuration A. It's like we never went over time, and we got the task done on an average of one to two seconds less time. It's controllable. Adequate with a tolerable pilot workload. Satisfactory, I'd say it is. All pilot compensation is to be able to estimate at the top. The most difficult thing is to get the power set

just right so you cruise right up on the point, stop it, consider yourself stable and get away from it. That's where the pilot compensation comes in, I give a rating of 3.

[For VCRs:] Attitude cues? I actually think they're quite good. I find that I'm amazed that on this checkerboard I can get by with a fairly aggressive maneuvering, and not find myself floating around on the checkerboard too much. I think that's a good indication that an attitude is going well. I don't have a good sense of controlling precisely at the top. It's just that I don't mess with the controls, the aircraft even with a rate system in it seems to stay pretty stable so I think I'll give you a 1-1/2. Horizonal translation rate? Probably 1-1/2. I do find myself cruising up probably, 1/2 a square or one square, so on some level I'd like to be able to knock down that translation a little bit, but there's two ways at looking at it. It's not bad, in general, in turns of big numbers. The problem is that I don't perceive myself moving. This has to do with inability to sense much of a checkerboard orientation when you're at the top. Now you don't really get good strong cues as to what your translations are, so the worst I'll do there is a 1-1/2. Vertical translational rate? I thought it was pretty good. The sense of vertical motion is really good. The difficulty in doing the task is not something in motion, but being able to control it knowing the dynamics of the vehicle. They certainly give good feedback, especially at the top, and actually good feedback at the bottom. Vertical translational rates, I'll give you a 1 for that.

Run 626 (Dash/Quickstop.) Once again, the task essentially is a no-brainer. You have a real good IP position, 25 feet, 10 degrees nose down, bleeding off to about 7 degrees. Once you have the acceleration going, it gets you 60 knots right about the center of the line. I'm finding that I'm sort of changing the way I'm looking at the end there. I find that the task doesn't look nearly as difficult as it has in the past during the other simulations. I actually see this being a little bit easier to do than the last time when I did Configuration A. There's actually a lot of room down there to do your final deceleration, so if you kill off your first 30 or 40 knots on your way to the last pylon then sorting it out at the end it works out fine. You can easily stop from going over the line to get the pylon out of the right window with no problem, and be in a nice stable situation at the end so I find myself being very comfortable with the maneuver. Rating, let's see: Controllable? It is. Tolerable pilot workload. Yes. It's certainly satisfactory. I'm finding that you've given me a large spectrum for altitude change. It seems like you could do it within plus or minus five without any great amount of skill involved here. With a little bit more practice, I think you'd probably do it plus or minus a couple. I'm actually surprised the aircraft doesn't balloon more from 60 knots as you're pulling the stick back, but I won't argue with what you have here. It seems like you can stay 25 feet plus or minus five throughout the whole task, and that is quite acceptable. That's actually the highest workload part of it. All of the numbers are very good. The amount of effort involved is probably like minimal pilot compensation because it's kind of hard to do that with what the aircraft's doing. When I look out and see the changing attitude of the aircraft I have a sense that I'm really ballooning, and I look down at the altimeter and see that I have gained more than five or six feet from the point at which I started the deceleration. I find that surprising, but once again that's the number so I'll take it the way it is. Okay, the rating is 3.

Attitude cues? I feel like I can be precise with it. Let's give it a 1 there. Horizontal translational rate? Once again, I can't tell you what the rates are. I could look at the airspeed indicator, and I find that I'm accelerating. I don't get strong cues from the board, though. In terms of the actual control of it, I'm not really controlling airspeed, I'm controlling attitude here. I'm just trying to set an attitude that looks like you're going to get 60 knots at the point where the color changes on the yellow stripe. That's actually what the control task is as I see it. How are we controlling horizontal translational rates? I think we're doing pretty good. We're being precise at

the end. I don't think that the end game is terribly demanding. It seems to work out okay. Let's give you 1.5 for the horizontal translational rate cues. Vertical translational rates, seem to be able to be aggressive. Precision seems to be good. I'm a little bit off by the perception I have. If I wasn't looking at the radar altimeter it would lead me to try to overcontrol it so I'm going to give you 1.5 for the vertical translational rate.

Run 627 (Sidestep). That's the best run so far on the lateral sidestep. Part of the goodness of the maneuver comes from just getting a sense of where you want all the visual cues to be. I have a hard time not encroaching upon the front side of the line so as I keep doing these more aggressively. In the morning I had a tendency to sort of push forward to the line then smoothly roll in to the angle of the bank, getting pretty close to what you wanted in terms of speed. Getting roll angles of at least 15 to 20 degrees, looked fairly good. Very good precision in rolling out. It's probably like a third of a square shy of being all the way to the right hand side. Going to left, I think I got it pretty close to right on the line, and back on the center, I thought we were pretty much on the line, both terms of the lateral positioning and the longitudinal positioning. Longitudinal positioning was much better than I've done on any of the other sidesteps in the past. It was a comfortable maneuver, and I thought the precision was certainly acceptable. Altitudes were plus or minus five feet. It's controllable. Certainly tolerable pilot workload. Satisfactory? Yes it is. No pilot compensation required for desired performance? That's the most difficult part of the task for me, preventing the forward translation it seemed to just fall into. It's something about the visual perceptive that I want to slide forward, and I have to keep thinking about feeding it a little bit of aft stick or at least thinking in that direction to keep myself on the line. That explains the 3.

Visual cues: Attitude, I've had too many problems with. Precision seems to be acceptable. I see a little bit of lateral bobbling. I perceive a little bit of a confusion factor between the motion base, which tends to be a little bit wishy washy laterally, and the visual scene, and the stick dynamics, so I'm sort of getting all three of them a little bit out of phase with each other. Still, this doesn't prevent you from doing a fairly precise job of the task. I can be quite as aggressive as I would like. Precision appears to be good, but not quite as good as I think it should, so I'm going to end up giving you a 2 for the attitude cues. Horizontal translational rates? I seemed to have a good control of the rates. It was more attitude control than it was airspeed control. I'm looking for something that feels acceptable rather than trying to hit some number in terms of lateral translation so it's hard to know what to measure it against. I feel that my sense of control of the rates is probably around a 1-1/2. Vertical translational rates seemed to be quite good, and I really didn't make any great effort to use anything other than sort of a subtle feeling for the board. It seemed to stay within the plus or minus 5 feet so I would be inclined to give you a 1 for the vertical translational rates. It is a task that very easily can drive you off your target altitude, and I was surprised by how nicely we stayed on it.

[Comment card:] Is flying technique modified because you're flying a simulator? Not really. There are some things that are different, I find that I don't work as hard in the simulator to get some of these visual cues that are measures of precision as I should. I think it's just the fact that everything is so soft. You try to fly between pylons, and so what the heck, so you do shave them a little closely. You couldn't do that in a helicopter, but you know that you can do it here so you actually change your strategy a little bit because you don't have a rotor to worry about. I think because in the simulation the CGI is less vivid, and less compelling with detail, I tend to take it more seriously. Even though you've worked very hard to give me straight lines, intersections, and certainly volume intersections on the checkerboard and things like that, I tend not to take it in my working strategy quite as much as I do with a real aircraft. Aircraft response? I don't think it was necessarily crisp. It's not sluggish. I think the motion cues are just a tiny bit better on this system. I would say,

yes, the cues are valuable for control. I think it's better than a fixed base simulation would be. I don't know how much better, but I feel more comfortable with it.
Slightly better than the last configuration, Configuration A. Motion/visual cues did seem consistent. I don't think they're perfect, but they're also not such a mismatch that they create any feeling of nausea. I guess that's about it. No deficiencies other than that. The scene just isn't as compelling as the real world is. I think that I have to say that this data base, as it's set up right now, is darn good for the task that you set up. I think it's satisfactory within the limitations of the CGI that you're working with. I find the colors acceptable. I find that you reached a really good compromise on the design of the checkerboards so that you don't have every square filled. It's useful, but it doesn't hammer you with a lot of detail that is hard to generate by the computer, and may be not that useful for you. I think you've done a very nice job of putting it all together.

Low-Bandwidth Rate System

[Runs 630 and 631: Comments lost.]

Runs 632 and 633 (Slalom). It's certainly controllable. Tolerable pilot workload? It certainly is. Satisfactory without improvement? This is a hard one to call because I think you can do the task with desired performance, and it's not really a sense of working harder at it, it's just an easy task. It's one of those where the task has not started to challenge you yet, so I don't think this task is breaking out performance differences in terms of hard numbers for past performance, but it does break out a difference in the perceived quality of the following of the flight controls. You see the task, it's very straightforward, and I find myself winding through it. I feel like the aircraft is sort of clucking around. It's just not a nice smooth trajectory. Although I'm getting desired performances there's something mildly unpleasant about what I see. Somehow that factors in; I don't think that factors in to the numbers. Here's one place where aircraft characteristics are quite good. It's minor but annoying deficiencies, compared to fair some mildly unpleasant deficiencies. In this case, it'll give us a 4 with some clarity. Minor but annoying deficiencies required moderate pilot compensation. I'm not too sure about the moderate pilot compensation, but the deficiencies are annoying because they give you a sense of not having direct one to one control, and being able to generate a smooth flight path, and that's the problem. That's why the rating of 4.

Run 634 (Bobup/Down). Now we're going back to the direction of not being able to perceive the differences. This task is done actually quite well, and quite comfortably. I did notice some uncomfortable sluggishness going over to the targets from the IC position. I got over there, and I found that just watching the nose attitude against the horizon, it seemed like there's a lag in it. If I was guessing I would say the problem is the lag in visual, but actually it's not obvious to me. There's something obviously wrong, and kind of sluggish about it, but the differences aren't big enough that I can grandly point to something, and say that's the problem. Actually flying the task works out quite nicely. I found that in all three climbs there was very little special effort required. Sorting out when to stop, it seemed like it came out right on target. It was plus or minus 1/4 square, something like that, and back down. Although we bobbled a little bit vertically, we still were within the plus or minus 5 feet limit, and quite comfortable. It was actually quite easy to fly. I don't see any degradation in it over what we were doing this morning. It's controllable. Tolerable pilot workload? It is. Satisfactory without improvement? It is. Pilot compensation is or is not a factor for desired performance? Actually, I'm going to give you a 2 on this because on those three data runs they looked quite good to me. They're comfortable time-wise, comfortable distance-wise, and the special control inputs required looked to be satisfactory. I've got no complaints so 2 is the rating.

Configuration N (Low-Bandwidth Rate)

Run 636 (Hover). I think I saw a little bit more oscillation there. It's hard to say. You look at it once, and you see some small things there that aren't necessarily going to be there the next time. At some level, I think perhaps I should be making more runs with the system to sort of even things out to make sure I'm actually seeing everything that's in the flight control system. But we're going to take it off this one. I find myself having a very difficult time ever totally stabilizing the vehicle. That indicates to me that there's a delay some place, either in the visual, in the flight controllers or something. I'm just slightly out of phase with it. Not grossly, but enough to never settle the aircraft down. That appears to be mostly in pitch. Very little of it in roll that I can see. It's controllable. Tolerable pilot workload. Satisfactory without improvement? I'd say no. Minor but annoying deficiencies. The deficiency is the pitch response. A little bit of lag in there someplace, and it creates a very difficult time in actually stabilizing the vehicle. I don't think it was stable the whole time I was running the task. Desired performance requires moderate pilot compensation. Good altitude. Reasonably good position hold, but just never had a stable aircraft. This does not look like a zero-wind condition. It looks more like you're out there with 5 or 10 knots of wind with a rate command system.

Run 637 (Vertical Translation). That generally looked like a nice stable maneuver at the start. As I started getting down on the cones, and getting closer to the ground, it actually looked like you had a ground effect model in here. As soon as I started looking back and forth, and not concentrating on the plane in front of me, I started really bobbling around. In this case, it not only was longitudinal, but also lateral. It was quite striking that I could look away, and not be able to hang on to the visual scene like I thought I should. It would be very uncomfortable at the bottom. Interestingly enough I think the performance stays at desired because the altitude hold was okay. The position was good. I can't actually complain about the actual performance of the vehicle. It's just the way that all the oscillations go around it. It's controllable. Tolerable pilot workload. Satisfactory without improvement? I'd say no. I think we're back in a 4 again. Minor but annoying deficiencies. Desired performance requires moderate pilot compensation. The rating is a 4, and that's pretty accurate.

Run 638 (Slalom). I think this task felt very much like the last slalom. There's a real sense of being out of sync with the controls. You do hear a lot more noise, you feel a lot more transport motion. I think because we're getting more motion, and more changes in the velocity of the carriage, I actually pick that up. It's not something that I see in the visual, and it's not something I'm doing with my hands. I think what's happening is with the lateral motion base. It really jumps out at you much more. It's sensed in me as a lack of coordination going on around the pylons. For some reason, I have a tendency to be shaving them closer. The last two times I flew the pylons, instead of feeling comfortable with carving nice round turns to stay within the three squares on each side, I find myself having a lack of good predictive control, and shaving the pylons closer. It's still desired performance as long as I don't hit them. What I actually sense is I'm falling back from having precise control of it. Once again, it looks like a delay in the visual system that causes me to be driving the aircraft harder than I have to in order to get the performance out of it that I want. Unfortunately I'm hard pressed to tell you what's actually going on. The rating: Certainly controllable. Tolerable pilot workload. Satisfactory without improvement? In this case, I think I'd have to give you a 4. Minor but annoying deficiencies. Desired performance, you get airspeed, altitude. Displacement is okay. Moderate pilot compensation is probably a good description so the rating is four again.

Run 639 (Bobup/Down). I see a difference between this bobup and the last. I expected on the last bobup to actually see some differences, and see negative things in the other task carried over into the bobup, and they weren't there. It really looked quite good here. I found that everything was a little off kilter, and I had a hard time stabilizing at the bottom. My ability to anticipate cleanly at the top where I should stop was poor. I don't think I got one right on. The first one might have been close. The other two were off by at least half a square, probably no more. They were good enough, they were where you wanted them to be, but no great sense of precise control. I think your criteria for desired performance is actually quite wide here. You don't have to actually hold it there for more than a second, or some fraction of a second, just to say that it's stabilized. Back down, I find I'm having a difficult time smoothly pulling it to a stop position, and not having such large overshoots. This was just a degradation of the last time we did the bobup. As far as the rating: It was certainly controllable. Tolerable pilot workload. Satisfactory without improvement? Again I'd say no. I think you could say that you're in the desired level of performance, but moderate pilot compensation required. The hardest things are anticipating both the stop at the top and the stabilization at the bottom. On two of the three, I thought the XY position was satisfactory. The last one actually crept up a little bit. I don't know what your requirements for that are, but it wasn't quite as good as it should be. I think a rating of 4 is satisfactory.

Configuration E (Low Bandwidth)

Run 640 (Hover). There's obviously a big difference in the motion system. It must be in a combined control and visual system. I can see a considerable lag in pitch, roll, and collective. I also see an abruptness in the directional axis which makes the thing difficult to fly. I think the lag, as I see it, is probably responsible for what looks like a near-PIO kind of a small-amplitude, fairly low-frequency oscillation about the hover point. I've seen it ever since I've been flying this particular task with this system. I'm beginning to think that it's pretty consistent. The delay is eating me up. When I do the hover task, I find that as long as you don't disturb the aircraft, you're like any other aircraft in a zero-wind condition. You will probably stay fairly stable, but as soon as you start trying to correct for small changes, it's very easy to get into a longitudinal oscillatory type mode that never really got any better. It's the first time, I think, I've ever had really serious problems with the altitude control. Throughout here, I don't think we get more than four feet away, but in the past we've been able to halt two quite nicely. In here, when you get into the swinging oscillation, you find that you start chasing a little bit with the power lever in collective. The longer you fly it, the more you upset it. The more you upset it, the worse it gets. It is quite hard to correct for. Okay, let's see, the rating: It's controllable. Adequate? Yes it is. Satisfactory without improvement? I definitely say no. I don't think you have desired performance. This is the first one that I would take out for altitude control. I think we probably maintained the XY position satisfactorily. The altitude control, and the resulting altitude deviations, were down in the adequate category. I would say that moderately objectionable deficiencies was probably accurate. Adequate performance requires considerable pilot compensation. That's a 5, that's probably quite accurate.

Run 641 (Vertical Translation). Vertical landing task shows the same problems that were exposed by the hover. They're even worse because to get into pitch, roll, and collective axes, you just make the straight line descent and descend to the target. I found out in this task you start to expose lateral PIO as well as the longitudinal. I found they were far more difficult to be precise for the aircraft. I could not stabilize the aircraft long enough in pitch and roll to get a good estimate of what the line of sight was with respect to the vehicle. You look at the target, you're trying to figure out is it attitude or displacement that you're looking at. In this kind of task, you've got to get the attitude stabilized so that the perspective of the target is constant so then you know how to drive up and

down that line to keep the targets in the same spot. Here, because you're bobbing around so much it's very difficult to determine exactly where that line is at. Generally not a very well executed maneuver. It's hard to envision in comparison to most others that you looked at. The vehicle is still controllable. Adequate performance attainable with a tolerable workload? Just marginally. You can still do the task. The divisional attitude that I think Cooper and Harper had, I think that you could say that you can still get adequate performance out of it even though you spent a lot of time oscillating around. Certainly not satisfactory without improvement. Very objectionable but tolerable deficiencies is probably accurate. Adequate performance required extensive pilot compensation. I give you a rating of 6.

Run 642 (Slalom). This task really points out the deficiencies in the lateral system, maybe even lateral/directional. It's kind of hard to tell what you're doing. The first thing that is obvious is that the carriage or the cab is spending a lot more time in motion. You can hear the gear noise much more audibly, and the system seems to have sort of a tick in it. You can feel it sort of clicking down the track. I'm not sure that's the sort of thing that is unique in the configuration, but maybe it's something that's kind of a module in the simulator today. I've not heard that before, but during the practice runs I could hear kind of a ratchet sound as I traveled up and down laterally. When you do the slalom you get a real sense of being out of turn coordination. There was 35 knots, and you should be able to very smoothly wind the aircraft through the pylons. If I was trying to fly a real aircraft, what I would feel is that I was trying to skid the turns. It would be like you were throwing the tail out in each one of the turns. As you sweep through you swing the tail far more to the outside in each turn than would be required to have a coordinated maneuver. You really feel that here. I'm not looking down at the ball so I can't tell whether you're actually sensing that meeting some semblance of lateral acceleration in o the ball or just allowing me to experience it. It's uncomfortable. It gives you a poor sense of lateral/directional coordination. I can't say that it's actually disruptive of your senses or nauseating, but it's just uncomfortable. It tells you that the vehicle is not flying the same way it appears to be flying in the visual system. I think airspeed control was pretty good right up to the point where I started it, and I dropped it by a couple of knots right back. I think we held airspeed there reasonably good through the course. Altitude was very constant. The 3 square requirement is actually not a problem here. The performance I think turns out to be desired. The problem is that the thing doesn't fly very well. Controllable. Tolerable pilot workload? Yes. Satisfactory without improvement? I would say no. Aircraft deficiencies or characteristics? This is probably the only place it will show up. Minor but annoying deficiencies. This is almost one of those that I'd like to give it 4-1/2. Let me think about it. Well, I don't know quite how to use the scale here. I find that the actual performance of it is desired. Minor but annoying deficiencies is probably a little bit understated. Desired performance requires moderate pilot compensation. Pilot compensation isn't really a large factor here. It doesn't prevent you from flying the vehicle through the simple task. This task is simple so I think what you're seeing is a reasonably degraded flight control system with a task that doesn't expose it. You end up getting desired performance out of it. You find the lateral motion that you're putting in the cab, I find to be uncomfortable, and inappropriate to the task, but it doesn't prevent me from doing the task. It looks like a rating of 4 is the end result of all that. The lateral motion is inappropriate to what the aircraft is doing going through the slalom. First of all, I don't think the washouts are very good. You feel a tremendous amount of lethargic sort of large amplitude motion that's inappropriate to the task. You don't really see the aircraft doing that. What you're feeling is a sort of thing that would, in a real world, result in having the aircraft doing large out-of-track maneuvers. I just want to make the comment that I don't see the aircraft doing that as it goes through the pylons. I certainly feel it in the seat of my pants, and of course, you hear this ponderous rolling back and forth of the motion base.

Run 643 (Bobup/Down). In this task, what appears to be a delay seems to factor into it. I found that it seemed like the closer the delay, the onset of climb rate was harder to detect. The best cue for how fast you're climbing is to see the crossbar, and not going up to the wires, at least for me. I found that it was real easy to put too much power in, and leave it in too long. At the time I finally found the crossbars, when they came in to the field of view, I slipped right past them. Much more of a problem of overshooting at the top because of what appears to be delays in the flight control system. You do more bobbling at the top than when you come back to the bottom because it is an aggressive maneuver. For a lack of a better term, it's sort of a manhole cover maneuver where you just sit there in one place, but you have a continuous roll/pitch motion trying to sort the thing out. One of the bobup/bobdowns also had an oscillatory vertical the same time we were doing the pitch and roll things. It was actually a very uncomfortable maneuver. It's the sort of thing that you would really like to stop flying it, let loose of it, and then grab it again, and try to sort it out because it's very obvious that you're driving it, and just going unstable, it's hard to get it to settle down. It's certainly controllable. Adequate performance attainable? Yes it was. Satisfactory without improvement? I would say no. I think we got desired performance. Minor but annoying deficiencies. Actually this is one of those not unlike the last where the actual aircraft characteristics are more like for a 5. We've got moderately objectionable deficiencies. I find that I have to guess about the flight control system. Part of it, I think, may be the mechanical characteristics. I find that I do a lot of oscillating around the ten point, and there's nothing in this task that should require that. I just find that I can't catch up with it. This is one of those things where I will break the rating between a 4 and a 5. On one hand you get desired performance, but you're doing a lot of extra controlling and compensating to hold on to it. Actually moderately objectionable deficiencies is pretty accurate. What you're really doing is you're getting desired performance with considerable pilot compensation the way it works out. That gives you a rating of 4-1/2. That's kind of cobbled up, but that's the best I can do.

Configuration D

Run 644 (Hover). Assuming this is a slightly different configuration, perhaps with a little bit more lag in it, I find that there's a little bit more oscillation both in pitch and roll. When I move off the initial condition here, and move over towards the cones, just small inputs in pitch will yield no discernable change in the attitude. Based on the visual scene, I can feel the motion base sort of chugging a little bit. I assume it's responding to what it senses as a small change of control positions or is working very hard to give me some kind of an illusion. I find that it's just not subtle enough. It's just that this small input that I'm putting in should result in no sense of anything other than just a smooth movement over to the cones. That's my first clue that something is amiss in the motion system or at least nonoperative. The second thing I think is the magnitude of the oscillations. Although I seem to by and large hold the aircraft stable, when I do start to move, I'm finding that it seems like the aircraft gets farther away from me prior to being able to pull it back in with a corrective input. I find that mostly in pitch not so much in roll. The altitude was good. I think the positioning was good. There certainly was no problem for keeping them in that lower part of that window. Control was okay. Pilot workload was okay. Satisfactory without improvement? I would probably say no. Minor but annoying deficiencies is probably accurate. Desired performance requires moderate pilot compensation, and I think that's fairly accurate. Pilot compensation in this case appeared to be mostly in pitch maneuvering. You sense that things were happening that should make sense to you, and don't necessarily. You feel the motion base working, and it's almost like it's sort of churning around. You know it's working, but you don't see anything that's beneficial for you.

Run 645 (Vertical Translation). In this task I start to see more of the problems of the motion system. I see what I was trying to say earlier, in between taped comments. Small inputs when you're in close towards the target, particularly in roll, are supposedly used to move yourself very carefully towards the target. They actually seem to precipitate some kind of a feedforward of the roll input which is sufficient to make you take the control input back out prior to anything ever happening. I found myself down close going control in, control out, control in, control out about the same amplitude and never moving the aircraft, I think responding subtlety to the seat of the pants cues, and not to the visual cues because they are not changing efficiently. Flying is a little bit sloppier all the time. I think each one of these configurations seems to result in a little bit worse overall holding of position. I find that I tend to wander around a little bit more. I'll see the displacement start, and I'll start feeding in the control, and nothing happens, and I overcontrol it. I'm getting to the point where I don't find the flight control system that responsive nor that much fun to fly. I feel like I'm working a lot harder than I would need to get a simple task like this done. On the HQR scale: It's controllable. Tolerable pilot workload? At least adequate performance with tolerable pilot workload. Satisfactory without improvement? No. Moderately objectionable deficiencies is probably reasonable. Adequate performance requires considerable pilot compensation. In this case the altitude following is poor. My ability to get the aircraft in close in a smooth fashion, and then bring it back out, is much reduced so adequate performance as far as I'm concerned requires considerable pilot compensation. Something less than extensive so it sort of homes in to a 5 as a rating.

Run 646 (Slalom). The task is done, I think, certainly to desired standards. The only thing I can see wrong with it is about halfway through we were at 34 knots instead of 35, and that's absolutely beyond my ability to control it precisely in here. Airspeed control was actually quite good. I think altitude was okay. The task was comfortably done, and I think more comfortably than sometimes in the past because I shaved the pylons more closely. First of all, there's no requirement in the task to do anything other than miss them in the fuselage. You would never be able to fly that closely to them, I think, with just a basic aircraft with a normal 40 to 50 foot rotor system. What you end up doing is being able to honor the requirements of the task, never ever come close to going beyond three squares, and have a task that doesn't really excite the lateral motion. In the practice maneuvers when I came through here, when you go out, say, a couple squares either side, you actually start to feel the lateral motion overshooting. You get the same sense that I was trying to say this morning of the tail just skidding on each one of the turns. It actually feels kind of sloppy. The sloppy feeling is essentially by the racing sound of the track. You hear it spool up going one direction, and then you hear an abrupt stop, and then you start spooling up in the opposite direction. There's something about the timing of the sound — it actually gives you a large sense of this being out of phase sort of thing, and you do also feel it in the seat of your pants. One of the things I wanted to say earlier, that shows up when you do just a quick set of impulses and step inputs into the axis prior to doing anything, you find that pitch, roll and collective seem to be pretty tame. When you put a very small step into the directional you get the same lag basically, then you get a very noticeable lateral bump. It's not directional, it's just lateral in the cab. It's totally out of character with the other three axes which have very smooth onsets, and with the exception of the lag, characteristically acceptable shaping for the control input going in. Directionally you have this very interesting bump so that would be my first clue that's there something in the directional system that feeds in to this slalom task. Of course it is a lateral/directional task, you're using a little bit of rudder as you go around these things. I'm not going to try to figure it out how it's all put together, just that it feels mildly uncomfortable. This last run that was made for the slalom had a very low lateral excursion. It didn't excite some of these things that I've seen before which I suspect are still in this flight control system. They were probably in a worse condition than they were in the last configuration. Okay, it is controllable. Adequate performance is attainable with tolerable workload.

Satisfactory without improvement? I would probably say yes. There's certainly a desired performance out of it. Fair, some mildly unpleasant deficiencies, and that has to do with this sense of skidding around the turns when in fact you're not really seeing that visually. Minimal pilot compensation required for desired performance? I think that's accurate, and the rating is 3. It looks like the rating is better than the system actually feels.

Run 647 (Bobup/Down). My perception here is the lags. I think they are larger in this configuration than the last one. They are showing up strongly in collective where you need to put a large input in to get the aircraft moving. You can't see the cue that you're going to use to stop it. You actually get more rate buildup than you really need so the tendency to overshoot the target is more severe. That plays more strongly into trying to correct your initial overshoot because you end up using a large control input. It takes a while for that to take hold, and of course you're overshooting the opposite direction. I find that's eating up the performance at the top, which I think unfortunately still shows desired performance. You could do a lot of bouncing around up here, and you still stay within one half of a square. I see it much more strongly at the bottom where I'm trying to get down quickly to make up for any time that I've lost trying to stabilize. By the way, there's not much semblance of really stabilizing at the top. You see the thing steady for a split second, and that seems to be enough. I go back down, and I find that I'm bouncing. Fifteen feet is the intended altitude, I'm bouncing like 10 up to 20 with no problem at all. I really don't have a good sense of control. I'm not crashing, but there's enough lag there that the precision is not at all good. Controllable? It still is. Adequate performance attainable with a tolerable pilot workload? The answer is yes. Moderately objectionable deficiencies, I think, is the most accurate of the aircraft characteristics. Adequate performance requires considerable pilot compensation. On some level I don't think we ever went out of your desired standards with exception of the 14 second round trip time. By and large the altitudes are okay on the top, and at the bottom it seems like the XY positioning is satisfactory. What I'm seeing as being the big problems are the overshoots and the inability to get any precision out of it. I'm definitely not pleased to give you a 4 for that. I think the thing that drives it there is moderately objectionable deficiencies. It's a fact that you end up pumping the collective a lot, and I think that considerable pilot compensation has got to outweigh the fact you're still getting desired performance so the rating is a 5.

[Comment card:] Is your flying technique modified because you're flying a simulator? Boy, you bet. The delays in this particular configuration are quite noticeable, more so in collective than I think any place else. They seem to be roughly equivalent across axes, but collective shows up the worst because you're being the most aggressive with it. The next axis that shows up is typically the pitch axis, and that is in the hover task and the landing task. I think the only reasons you don't see it as badly in pitch is that you're doing an almost stable standing task in hover and landing. In here, you're working the controls for all they're worth, and having a fairly poor set of cues to work with because you can't see the crossbars. You're climbing up to it so technique modification, of course, you can't see the targets. That's a simulator artifact. Number two, the delays are just long enough that it's very hard to be precise. Comments on aircraft response? Appears not sluggish, it's just that you can't get the precision out of it because you can't stay in phase with it. How did the motion cues affect your control of the aircraft? Valuable for control, yes and no. I think the sense of vertical motion in the bobup is nice to have. Unfortunately, when you get into any kind of oscillatory situation then the motion actually becomes a detriment. As long as you're doing just an onset, I think it gives you a sense of accelerating, but once you take the input back out then I think it gets out of phase with your body, and actually becomes a detriment. Certainly in the slalom maneuver, I think that the lateral characteristics of the motion system are highly suspect. They don't feel comfortable to me, and they don't look appropriate for what I'm doing. I don't like the auditory feedback either. I could stand

the auditory feedback if what I was feeling in the seat of the pants was characteristic of all that commotion going on. Compare this motion system with other systems flown in this experiment? It seems to me that the motion system is essentially the same. What I'm seeing as being different is the lag between control input and output in the visual scene of the motion. About the only thing that I can pick out for sure is the correspondence between the stick and the visual system. The vestibular system is being fooled by the motion system, and I'm pretty hard pressed to tell you what I think is happening. I guess I could sit down and dissect it more, but I'm not sure that's what you're after. I see a lag between the stick input and the visual. I go step with the stick, and I see a thousand one and then I see the motion. What I think I see, is this system being slightly worse than the last one I flew, and that's just perception. What I want to try to say, I can't tell you exactly what the motion system is doing. I think it generally follows for an input at least from zero state to the first input. I think when you start working the controls I get a sense of the motion system not helping me any. I start to feel like I'm out of phase with it. I think, for instance, the effort up by the cones when you're trying to do the landing task, when you start putting a little bit of oscillatory roll input in, you really feel the lateral system bumping you. You get the sense that the whole motion support thing is sort of bumping back and forth. It's very clear that's not the kind of motion you expect to get out of the aircraft. The actual aircraft might be moving, but what it would give you in terms of sensory return is not the same that you're getting here with these sort of sideways bumps. I find that to be probably the most glaring error in the motion system. That and the sense of poor lateral characteristics going through the slalom. Okay. The rest of the visual cues seem consistent. Once again, the best I can characterize is when you put the initial input in, the onset feels good. When you take the control back out, and expect the motion system to follow, I think that's when things start to get out of phase a little bit. At least my senses are being in phase. Were there any unusual, conflicting, uncomfortable visual/motion cues? Uncomfortable only as I've already described with far too many words. The feeling of nausea? No. Any other obvious deficiencies? I think we beat it to death.

Configuration D (Low Bandwidth)

Run 648 (Hover). It's very clear just playing around with this system that the bandwidth looks very low. You can probably control even a modest amount and get virtually no output out of the vehicle so the phase lag is incredible. It has really small inputs before you start seeing the response of the vehicle. In that response it's quite the slug, however, up around the cones it doesn't seem to make that much difference. It seems like you could still do a very reasonable job of holding both altitude and position with very reasonable pilot workload. It just shows that it's not a very aggressive task so therefore it doesn't demand much with the flight control system. As far as the rating is concerned, it is certainly controllable. Tolerable pilot workload. Satisfactory without improvement? I'd say it is. Fair, some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. There is some amount of extra work that comes from trying to keep up with the slow falling off at the point, and having a very low bandwidth to catch up with it. It actually is a molasses-like system, everything is slow. As long as you can get in tune with the fact that it's a very slow system then your precision goes up. I would say that a rating of 3 is acceptable.

Run 649 (Vertical Translation). Surprisingly, I don't see any real degradation in the performance for this task. It's significant to note that there is no time requirement on it. Since you could do it at your own pace this really low bandwidth flight control system as I see it could be used to some advantage, just don't upset things. I find that I was able to get a good precision both down and up and back down, and no complaint. I don't think much of the flight control system on general principals, but for this particular task I can't see a degradation. It's controllable. Adequate

performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? It looks okay for the task. Fair, some mildly unpleasant deficiencies. It's probably more accurate than saying that pilot compensation is not a factor. I would not call it necessarily good, I would merely say that the flight control system is such that I can do this task and get desired performance out of it without screwing anything up. Minimal pilot compensation required for desired performance; the rating is a 3.

Run 650 (Slalom). It's a fairly good start here on airspeed and on altitude. Once again, it doesn't seem like much of a task. Other than that, I don't see anything different in the general response of the vehicle. It's controllable. Tolerable pilot workload. Satisfactory without improvement? For what we did there, I would say for that task it is satisfactory without improvement. There's fair, some mildly unpleasant deficiencies. It is a little bit on the sluggish side, minimal pilot compensation required for desired performance. I guess I could give it to you because I was less than 35 knots, but I'm not willing to say it was moderately objectionable deficiencies with considerable pilot compensation because it's truly not required to do this task. It's a really simple task so I'll give you a 3 for it and let you sort out how you'd really like to rate it, or you like to use the rating.

Run 651 (Bobup/Down). The toughest thing about this task is, once again, anticipating how to get the control input out and not to overshoot the target. I found that the overshoots were more challenging to control. In some ways, I never really did achieve satisfactory one-shot controlling. I'd overshoot, and I'd put a bunch of collective in the opposite direction and try to stabilize it. I think if you found that you actually made me stabilize it it would take far more than 13 seconds so what I'm doing is taking a look at it, stopping it, showing it's stabilized for a split second, and then going on down. The task reads stabilize for 3 seconds. Don't kid yourself, there's been no expectation in the last week that anybody would be up there for 3 seconds. What I was given was a very loose criteria that said: come to a stop, it'll be within half a square, and then you could continue down. That's a heck of a lot different than stabilizing for 3 seconds, and maintaining within the criteria. That's a challenge, just to bump it up, and bump down, if I were you I'd have a very hard time determining what the data really means. So, let me tell you what I did. I just showed that I was momentarily stable. Took fairly large inputs in terms of correction at the top. At the bottom the same thing. I found that I was using what looks like plus or minus 2 or 3 inches in terms of corrections — boom, boom, boom, trying to keep it between 10 and 20 feet on the recovery. It's just a very slow system. 13 seconds keeps us out of the desired region. I think if we were playing the game, I think you'd be way out of the desired region time-wise if you were trying to hold to the original specs. Pilot decisions: It's controllable. Adequate performance attainable with tolerable pilot workload? I'd say it is. Satisfactory without improvement? No, it is not. Moderate objectionable deficiencies. Adequate performance requires considerable pilot compensation, and that has to do almost entirely with getting that vertical control where you want it so you can stop reasonably well on the top, and come back down, and stay within the altitude criteria. I find that there's just no sense of being able to do it with one stroke. You put a full down power lever input in from the top going down, and find that you can judge well enough to be able to just pull the power lever back in and stop. If you'd give me the original baseline configurations, I'd think that was actually quite easy to do. I developed a sense where 15 feet was. Here, I find that because of the sort of a shape of the onset of the response, I picked up considerably more velocity going down than anticipated. When the sight starts coming in to view, and I want to stop, and I find it — whoa, I get far more rate than I can stop with a normal input. That precipitates a much larger input, and then you end up with two or three, four or five overshoots at the bottom. That's where the considerable pilot compensation comes in. It's not difficult to do. It's just effort and time consuming. The rating is a 5.

[Comment card: Initial comments lost.] ...It would be because of motion cues that you have to learn to use. They're not the same as in the aircraft. In many cases they're helpful. A number of cases that we talked about where I think they're actually a detriment. It's very hard to find a motion system that does everything perfectly well. Certainly the baseline is a heck of a lot better than where you're at right now. Comments on aircraft response: Crisp? No way. Sluggish? Very definitely. Now if you just do your basic steps, pulses, and sweeps, you find out that the aircraft really looks like a slug, and has no frequency response to speed cue at all. That's basically very Huey-like, or less. How did the motion cues affect your control of the rotorcraft? In this case I think the sluggishness of the basic response seemed to overshadow the sensibilities regarding the motion system. I didn't find anything to complain about. Maybe it was because I was so engrossed in watching the response of the vehicle to the inputs. Did the motion/visual cues seem consistent? I guess reasonably so, I wasn't as sensitive to the small bumps, or low velocity translations, I was trying to see that again, and I actually didn't. I occasionally find that you'd be cruising along, and if you just ever so slightly put in a lateral input of the most modest amount, you'll feel that there will be a bump in the aircraft that should not even be noticeable, but it jumps right out at you because you go — wait a minute, where did that come from? — because you have no sense of having put it in with a controller. So I think that's a good indication that there's a lot of subtle little things happening. When you get engrossed in some of these fairly dynamic maneuvers, you don't pay much attention to the small stuff. I suspect that it's actually the small and subtle things that either give you a good sense of reality or a neutral or a negative feedback from the motion system. Any unusual, conflicting or uncomfortable visual cues? Not really, no discomfort. I really haven't been moved on any of the other systems to sit there and try to frequency sweep them, but this one was obviously such a dog coming out of the blocks that it does seem like a reasonable thing to do. In the past I haven't been moved to do that so I guess it's just an indicator that this one was obviously different from the first two.

F. PILOT M

Baseline Configuration (Fixed Base)

Run 121 (Hover). For desired performance keep the cone in the lower half of the window — I basically did that. The cone should be reasonably stabilized. It should not be continuously wandering. I didn't really accomplish that. It was wandering quite a bit more than it was earlier. Maintain altitude plus or minus 2 feet — yes. Heading plus or minus 5 degrees — there was no problem. I didn't meet the desired performance based on the second one. I met adequate performance fairly easily. The HQR: Is it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? No. There's minor but annoying deficiencies. I'd say adequate performance requires considerable pilot compensation. I was using probably 1/8 to 1/4 cyclic in the fore/aft and lateral axes every one to two seconds to maintain or to get back to where I should have been. I'll give it an HQR of 4-1/2.

The visual cues: I would say it's fair. Looking at the horizon, you could see when the pitch attitude was changing so that was good. In roll, I had a pretty good idea when it was rolling. Horizontal translational, in both the lateral and the longitudinal axes, I would say those were around a 4. I didn't have very good cueing unless I looked right down at the cone to see if I was making small movements. When I did actually put in a cyclic, what I thought would be a motion to stop it, I didn't have any realization if it was enough or when it actually took place until I actually looked down at the cone, and I could see my relative distance from it. The vertical translational rate: I had a tower right next to me, and it didn't really move very much, so all in all that was fairly good too. So I'd say that's about a 2-1/2.

Run 122 (Vertical Translation). It is desirable to keep the cone within the lower half of the right window at all times, targeted to plus or minus two feet, and I met the target. Altitude is okay. Keeping the cone within the lower half of the right window is okay. The descent was very difficult, I actually moved forward, and I didn't have any real good cues. In trying to look down to the right, I'd lose all my cues just to see where the cone was. Additionally, I'd lose all my cues either forward, left, or right. Consequently that was very difficult to do, and I was really working hard on the collective, and on the cyclic. I wasn't really being real fast on it either. I was trying to do it fairly slow. On my heading, I believe I maintained within plus or minus five degrees. I probably got around five degrees off. I met the adequate performance, but I didn't really meet the desired except on the climb to 30 feet, and that was no problem for that. I kept the desired performance on that all the way. For my HQR, is it controllable? Yes. Is adequate performance attainable with tolerable workload? Yes. Satisfactory without improvement? No. I'd say, to maintain adequate performance requires considerable pilot compensation. Moderately objectionable deficiencies. I'd give it an HQR of 5. Mainly, the deficiency being that it was hard to notice when I was drifting forward and aft. Consequently on my rate of descent and rate of ascent, I had no real cues to ascertain how fast I was going. It was difficult to actually come to my 10 feet even though I did. I was having to work hard on my collective using probably plus or minus 1/8 amplitude, and in the collective I'd say every one to two seconds. In cyclic I was probably going plus or minus 1/8 on the cyclic, and in the fore/aft and lateral axes every two to three seconds.

The VCR ratings: The attitude? When I looked down at the cone, and I didn't really have any real good cues, I'd lose my references outside. I was doing fairly well just to see where I was in relation to it. I didn't have any other peripheral views, and cues were not adequate at all in any realm. If I kept my eyes outside, and just kind of glanced down to the cone then I could see the initial portion of it. At 20 feet high I could see fairly well because of the horizon. When I was lower than that it wasn't very good just because the ground was too close to give me any kind of discernible change in it. Consequently, I'd say all in all it was about a 3.25 in pitch. In roll, I didn't hardly look at that so I won't give it a rating. The horizontal and the longitudinal/lateral, I thought that was fairly difficult to discern. I actually started moving forward, and I didn't catch it until I was already moved enough forward to almost get the cone out of view or started to get to the back portion of it. I would have to say that was again a 4 in longitudinal. The lateral was a little bit easier because I had two cones there that I could see. I had two ways of actually seeing it, so in the lateral axis probably around a 3. The vertical rate was very difficult, to figure out exactly how fast I was going up and down. I didn't have time to look at my VSI this close to the ground from 20 down to 10 feet. I'd just try to get a sensation of how fast I was going or how well I was stopping. It wasn't real good at all so I'd say about a 4.25.

Run 124 (Pirouette). [Comments lost.]

Run 125 (Slalom). I was working pretty hard on this particular maneuver. I didn't have any sensation of what was going on, and I was having to constantly check inside and outside because the cues outside were not giving me the information I needed. When I looked inside I'd lose reference to what's going on outside so it was quite intensive maneuvering in order to stay within the parameters. Is it controllable? Yes. Is adequate performance attainable with a tolerable pilot workload? Yes. Is it satisfactory without improvement? No. I'd say moderately objectionable deficiencies. Adequate performance requires considerable pilot compensation, and I will say that it was a 5. I had no recognition of airspeed, and on my height or my altitude I was having to look outside inside, and I was working collective, I would probably say 1/8 to 1/4 inch collective input every 2 seconds. In the cyclic I was making a continual small longitudinal correction as I was flying. In

addition to this, I also made an 1/8 to 1/4 inch longitudinal every 3 seconds, and the lateral when I was actually making my turns. I think I was just putting one in, but on one or two occasions I had to put in one bank, and then add a little more to get the right amount of bank. It was a difficult task.

On the VCRs: The pitch attitude I didn't think was very good in this particular case. I didn't have any cues to show me when I was getting nose low or nose high other than the horizon. I didn't really have the chance to really look at that in the horizon very close at the time, so consequently I didn't have a feel for it, I'd give a rating of 4. In the roll attitude I really wasn't worried about it. I just had to put in one, I needed to get around the pole, so I wasn't looking for a specific roll. It was probably fair. The longitudinal translational rate was poor in that I didn't have any real cues showing me how fast I was going. I thought I had pretty well locked it down at the very beginning, but then as I started making some turns, I lost all of any type of cueing to whether or not my airspeed was staying. My longitudinal cue was staying constant. I would give that one also about a 4. Lateral? I didn't really have any so I won't comment on that. The vertical? When you're in a slight bank there are really no vertical cues. The only way I could see that I was climbing when I was in a bank was to look at my radar altimeter in here which showed me whether I was actually in a climb or not. I'd have to say that my cues in that were poor. I'd probably say that was about a 4.5 on the vertical rate, and that's all.

Run 127 (Bobup/Down). As far as the HQR, is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I'd say there are minor but annoying deficiencies, and desired performance requires moderate pilot compensation so an HQR 4. I was overcontrolling the collective at the bottom. I had no real cues as to what I needed to do, how much collective to pull in order to stop my rate of descent, and since I didn't have a really good rate on the rise and fall, the amount of collective was difficult to figure out. I also noticed that I started to back up once I applied the collective. I started to have to put in a little bit of forward cyclic, and I got into a little bit of oscillation there to try and stabilize at the end which would be a longitudinal cyclic application about an 1/8 or 1/4 inch for approximately every second for about four seconds, and then I could get it under control. Collective was actually up to 3/4 inch or an inch worth of collective movement in order to stop it. There were three or four smaller, 1/4 maybe up to 1/2 inch collective inputs, to actually get me back down to a stabilized altitude. What I did notice was that I could move the collective approximately 1/4 inch three or four times rapidly in succession. I had no real change on my altitude or even at a moderate rate so that could be why I was not really seeing any movement overall in altitude because it just wasn't catching up with it. Overall I give that HQR 4.

The VCR: The pitch attitude was not really very good. It was okay on the ascent and on the descent. In both cases I ended up having a nose high attitude when I started getting lower, and I didn't have any cues at all to show me that I had actually had a nose high attitude, and I was drifting back until I got close to the ground, and then I got some horizontal cues so I would say that's about a 4.25 in the pitch attitude. Roll attitude? I didn't have any. In the longitudinal translational, the cues when I got up in altitude, all in all they were fair. A little bit better than fair so I'd say about 2.75 on the cues. When I was down close, I could see the ground moving so I could see what I was moving back and forth. Other than that, I didn't really move back and forth very much. I had the bar at the top, and I could see the change. Vertical rate, I couldn't really tell my rate of ascent or descent. I could see that I was moving up, but I really didn't have much cue as to actually how fast I was moving up, and that's how I got a little overcontrol so I'll say that one was probably a 3.75 on the vertical.

Dash/Quickstop [No Run Number]. I met the desired performance, but it was fairly difficult to do. I had to work hard on the cyclic and also on the collective. I also got off a little bit on heading, but I did meet the desired performance. HQR overall: Is it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I'd say they were minor but annoying deficiencies, and desired performance requires moderate pilot compensation. I show an HQR 4 based on having both the collective and the cyclic inputs. They were small, about 1/8, 1/4 inch every two to three seconds, but it was still high for moderate pilot workload to do it.

On the VCRs: My horizontal translational rate again didn't have any good cues as far as my actual airspeed. When I was decelerating, I didn't know how fast I was decelerating. It was actually harder to figure out how much collective and cyclic you needed to put in to stop it. All in all, I'd say that was a 4. In the pitch attitude, I had fairly good cues on what my pitch attitude was. How they related with me stopping was a little bit more difficult, but the actual cues in telling me where I was, that I had a pitch change, that was pretty good. I'd say that was about a 3. In the vertical translational rate, that was a little bit harder to discern. When you've got to change your pitch, there were no real cues to show me that I was going up or down except to look inside to see my change in altitude. I will go with a 3.5 on that one.

Sidestep [No Run Number]. The side step was a very difficult maneuver. I never did it on the first try, but let me say what I did. It seemed like I had a difficult time maintaining desired parameters, and that was due to having no real cues on the fore and aft, or my distance from the actual line. Stopping and maintaining my altitude was fairly good, and my heading was okay, but my distance was not very good, so I would say it was okay to maintain adequate performance. As far as an HQR, is it controllable? Yes. Adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. I'd say adequate performance requires considerable pilot compensation. Moderately objectionable, I'd say it was an HQR 5. That was based on the high pilot workload as far as coordination effort, and without any good visual cues or sensory cues in this case, and it was a little more difficult. I was having to put in a lot of pilot control inputs throughout the maneuver. I would say cyclic fore and aft and lateral 1/8 to 1/4 probably every one or two seconds. Collective only down to about 1/8 of an inch every two seconds, and pedals probably 1/8 of an inch every two or three seconds on that.

The VCR: Pitch attitude didn't really have a whole lot of good cues, I'd say it was fair. 3.25 on the pitch attitude. Horizontal translational rate didn't have very good cues at all. I'd say it was around a 4. Lateral translational rate wasn't really something I was looking for because I was trying to move laterally. I didn't know how fast I was going, but I was going by parameters anyway so it didn't make that much difference. It was fair — I'd say that would be a little bit worse than fair so about a 3.5 because I really didn't know how fast I was going in the side. Vertical translational rate. Although I was maintaining my altitude fairly well, I didn't have many cues to do it. It was probably just looking in at the radar altimeter. I would say all in all that was probably 3.5 on that one.

Pilot comment card now: Flying technique modified before you're flying in a simulator? I'd probably have to say yes, just mainly because I didn't have any sense of those types of cues in the seat of the pants to give me anything so I had a tendency to glance in at my instruments quite a bit more than I would actually do in an aircraft. I'd look in at my radar altimeter, my pitch, and some of the other ones I was looking at today. I might look in at my torque and my rotor or something like that. It was just different instruments that I was glancing at than I normally would. Aircraft response was fairly crisp in all axes except for the collective. When I was doing the bobups, once I brought it back

down to where I was trying to descend to, I could get in to a PIO. With about 1/2 of collective, I could take it back out again, and put in some other input, and I'd never see anything. That was not a very fast rate, so it seemed like the collective was a little bit less responsive than the other ones. Motion cues affected control of the aircraft? They were valuable for control. If I didn't have any of the cues out here, I would have crashed. The lack of motion system, I felt that it was worse than it was when we had the motion because I didn't have some of those other little cues that I had before. Motion visual cues seemed consistent? No, because there wasn't any motion. If there were any unusual or conflicting, they're going to come from visual cues. When I was in roll, and I was translating sideways, I made a transition from a forward to a sideward, or a sideward to a forward at the same time then at that point I'd get a little squeeze. Maybe my body was expecting for it to be moving in two axis, and I was really not moving in any axis. Perhaps it moved a little bit so I got a little bit queazy in that. If I moved real aggressively, I could get a little bit of nausea. Not really any disorientation, just a little bit of discomfort when I did a rapid movement either in the pedal turn or a lateral turn. In the visual scene, the only obvious deficiency is that there are not enough vertical obstructions to give you more cues.

Baseline Configuration

Run 133 (Hover). Desired performance of keeping cone within lower half of window is met. The cone should be reasonably stabilized, it should not be continuously wandering. It wandered a little bit. Maintained altitude plus or minus two feet? Yes. Heading plus or minus five degrees? Easily, so I think I'm at desired performance. The only thing, it wandered just slightly. I'd say: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I would say yes. Fair, there's some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. All I was required to do was some small, less than 1/16 inch cyclic movements, approximately every two to three seconds. It may have been a little bit more than that, perhaps one to two seconds. They were very minor. There was just some very mildly unpleasant deficiencies. I give it an HQR 3.

As for the VCRs: Attitude broken down into pitch and roll, I'd say probably a 2-1/2. The pitch attitude had good definition, I could see for distance; however, when I got in close, it was probably one or two degrees. All in all, it's probably 2.75, a little bit better than fair. The horizontal translational rate laterally is quite good. It had good references to show me when I was over some squares. If I had any type of movement either in the distance, or close in, I could see it readily. I would say that's about a 2.25. The horizontal longitudinal? I didn't think it was very good for real precise hovering because that was the only area I was actually getting off. It was just a little bit on the horizontal longitudinally, I was drifting a little bit fore and aft, and I wouldn't really catch it unless I looked down, and I saw the cone was moving. All in all that was probably about a 3.75 on that longitudinal. Vertical? I didn't have any problems with vertical at all. I was staying within that one foot the whole time. My peripheral cues? I didn't have a chance to really observe them. I did have this wall right in front of me. I had the big donut around it which, if I got off, I could see the top a little more so I say that it was a little better so give it about 2-1/2.

Run 134 (Vertical Translation). Keep the cones within the lower half of the right window at all times — I did that. Keep target attitudes plus or minus two feet — I just barely did that, yes. I maintained heading within plus or minus five degrees. Adequate performance was met because I met desired. Okay, we'll go back to the HQR. Is it controllable? Yes. Is adequate performance attained with tolerable pilot workload? Yes. Is it satisfactory without improvement? No. Minor but annoying deficiencies. Desired performance requires moderate pilot compensation, and I would say

that's true. It was really a little bit more than minor annoying deficiencies so I'm going to go with an HQR 4-1/2 with moderately objectionable deficiencies, and desired performance requires moderate pilot compensation. Basically, what I was having to do: The heading was very easily maintained. The collective, I was probably using 1/8 and 1/4 inch collective inputs every one to two seconds on the descent trying to get a good rate going. I was having a hard time just maintaining an even rate. The cues showing my descent were difficult. I was, also, putting in cyclic. It wasn't very big cyclic inputs, but it was about 1/16 to 1/8 inch cyclic inputs. I'd say probably every second to a second and a half. That was both in the descent and the ascent. The difficulty was in maintaining my longitudinal reference with it. Lateral was barely okay. Longitudinally I was getting off, and when I was trying to put small inputs in, it was hard to actually figure out how much to put in. Consequently, before I had started building up a rate, then I'd have to take it out. All in all it was about a 4-1/2. It was based on the number of cyclic inputs and collective inputs I had to apply.

The VCRs: Pitch attitude was fair. I'd say it's a 3. In the roll axis, it was hard to really discern when I'm looking down out of the corner of the peripheral if there were any kind of cues out there to give me so I'd say about a 3. The pitch attitude wasn't as good as before, because of the angle I was looking out of. There was really no cue out there. On the pitch attitude I'd say it's about a 3-1/2. The longitudinal horizontal translational rate was probably the worst of all of them. I didn't really have much in my field of view showing me that I was drifting fore and aft, because I was trying to move a little bit, but I couldn't pick up a rate very well. I'd say that was about a 4. In the lateral rate it wasn't quite as bad because the cone gave me some type of cues. I also had the squares, right out in front me, and I could see if I was getting the type of rate I wanted, but it was still right about a 3. The vertical translational rate was not very good. I didn't have much cues. All I had was the size of the cone getting bigger and smaller to give me any cues, which is fairly good, but it's not super. I would say that was fair in the vertical translational rate.

<u>Run 135 (Slalom).</u> Desired performance is to maintain the maximum lateral distance from the poles at less than three squares. I believe I did that. Airspeed plus eight, minus zero. I did that. Altitude plus or minus 15 feet. I did that. Okay. Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? Yes. There were minor but annoying deficiencies. I can't go with a 3-1/2. It's actually a little better than 4. I did have some minor annoying deficiencies. I had difficulty in picking up my airspeed, although I got right down and almost went below 35 there at one point. I made an increase in the cyclic, and I brought it back up, and maintained it about 40. Maintaining it at 35 was really difficult, but within the desired performance. I'll have to go with an HQR 4 because it's not quite a 3. There was some minor annoying deficiencies. If I could go a little bit better than 4, then it would be 3-1/2, but since I can't, I'll go with HQR 4. What I had to do, more than anything else, was in the collective, I had to make some minor collective applications, only about three or four times, during the entire run. They were probably about an 1/8 or 1/4 of an inch to 1/2 inch of collective input, and they were probably as I made the turns themselves, so that may have been about four or five applications. Cyclic, other than making the rolls, was not too difficult. In the longitudinal axis, I found that there was just a little bit of difficulty in maintaining the airspeed that I wanted. That was requiring about every 1/8 cyclic application in the longitudinal axis about every two to three seconds. That was more, and it may have been 1/8 to 1/2 inch, somewhere in that realm of deflection. All in all HQR 4.

On the VCRs: The pitch attitude, that was fair. Big attitude changes were good. It was a little bit worse than fair, so I have to give that a 3.5. In the roll attitude, I didn't have any set desired roll parameters, so it was sufficient to give me what I needed for this maneuver. Consequently, that would be about a VCR 2.75. The horizontal rate, longitudinally speaking, it was the hardest thing

to pick up whether there was a rate building or not. That little change of airspeed was about six knots, that I had in during the course. When I was on my way up there, I actually got down to about 32 before I was entering the course. I therefore didn't have the airspeed indicator to go back and continually scan. That would have been the hardest thing to figure out, so I'd say that's about a VCR 4 on the longitudinal. The lateral, I didn't really have much use for the lateral rate so I won't rate that one. The vertical translational. I had the pylons there just to give me a rough guess of where it was. With any minor precise ones, I didn't have anything other than my radar altimeter setting over here. All in all that wasn't preciseness, it wasn't real good, so it's about a 3.25.

Run 150 (Bobup/Down). Desired performance: complete each bobup/bobdown in no more than 12 seconds. They were about 12-1/2 seconds. I was a little bit remiss in telling you when I was actually stable, and all that. I think that I was real close to 12 seconds, so meeting desired performance, I could meet it. Maximum overshoots more than a half square — I didn't do that. My last one was a little sloppy, but the other two were good. Overshoot involved no more than 5 feet. I didn't do that. I could meet desired performance. Adequate performance? Of course I could meet that. As far as HQR's: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? Let's see.... Again, I can't use a 3-1/2 where it kind of lies in that area. Let me see what it looks like: There were some mildly unpleasant deficiencies. I really kind of think it's going to be minor but annoying deficiencies. I think I could go with an HQR 3. It's fair, so it is satisfactory without improvement. There were some mildly unpleasant deficiencies, and it's minimum pilot compensation required for desired performance. The compensation required for desired performance was merely in the collective application. I did have just a tendency to translate aft, but the unpleasant deficiencies were not in the ascent at all because I pretty much nailed that; it was on the descent. I would have one collective input of approximately 1/2 inch to stop my rate, and maybe up to 3/4 inch in, probably a decrease of a 1/4 inch to 1/2 inch collective, and then I would just hold and see what washed out, as my altitude normally is within two or three feet. All in all, it wasn't much compensation or anything. I just thought it was easy to fly, so I'll go with an HQR 3.

The VCR's: Pitch attitude was fair. The roll attitude, I didn't see any. Both of them would be right around, I would say a 3. The reason they're not a little better than that, would be in the pitch. I did have a tendency to be just a little bit off on my pitch attitude and not really notice it too much, so I didn't have good cues to see that I did. Horizontal translational rate: About 3.25 longitudinal because I was drifting aft, and I really didn't notice it until I started descending, and I could see that I was actually doing it. I guess I'll give that a 3.5 because it was a little bit worse than fair. The lateral had the big tower right in front of me so it was good, about a 2.5. The vertical translational rate at the top was pretty good, and the bottom was okay because you could see the smiling face, and that bar at the top, but there's no real rate that you could see in the middle so all in all that's probably about a 3.5.

Configuration E

Runs 136 and 137 (Hover). I met desired performance. There was a little bit of wandering, I could hold it for about 20 seconds and then I would notice that I'm drifting a little bit, and I'd have to correct the slight amount of wandering. I feel that's still within the desired performance. As for the HQR: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I'd say no. The deficiencies warrant improvement. If I could not breathe, and could not move at all, and I had it set up, then it was perfect. However, if I flinched at all, or made any kind of input into the cyclic, then I got almost

immediate response in the rate. I'd start moving, and once I got into a loop, I got into PIO's the whole way. For about the first 25 seconds, I was really concentrating on my breathing, and how much I was actually moving. I don't think I moved the cyclic at all. I noticed then that I had a slight slow drift aft for my initial setup. I had to put in a little bit of forward cyclic. All I really did was just think about it. I couldn't even measure it, maybe 1/64th of an inch or something like that, that small. All of a sudden, I had a fast rate going forward. I started getting into the loop, and pretty soon by the 50th second or so I probably had up to, I'd say, 1/32nd of an inch or 1/16th of an inch of fore and aft cyclic movements every 1/2 to 3/4 seconds so that would be an HQR 4.

On the VCRs: Actually, any type of movement corresponded well with what I saw in the horizon, so other than my initial pitch attitude, if I had it set up correctly, then I would have recognized that I was actually drifting aft. As soon as I put that little bit of forward, I could tell that my pitch attitude changed. I'd say, all in all, it was pretty good. It's about a 2 to 2.25, right in that range, for pitch. Roll — I really didn't have any roll going, so it was about the same, probably about a 2.25 also. Horizontal translational rate, longitudinally, I could pick it up quicker than I was actually moving. I could see that I was drifting aft ever so slightly, so the preciseness of it I could actually tell very well, so about a 2.75. The lateral, I didn't have much, so I'll probably say 2.5 or so. Vertical, I'd say that's about a 3. All I had was the pole there, and then again the cones to see if I was moving. More than anything else, I relied on the radar altimeter more than the visual cues outside on that particular portion, so I would say 3 on that.

Run 138 (Vertical Translation). Desired performance: Keep the cone within the lower half of the right window. Carry out these plus or minus two feet. I think we went down outside of that. I got 3 feet. That's because I got into a PIO there at one point, and I don't really know if I met that or not. I got down a little bit below, and actually kept the cone within the lower half. I almost went outside the window once or twice. Heading, I think I actually got off by about 6 or 7 degrees at one point because I was so intent on watching the other stuff I missed that. I don't think I met desired performance the whole way through. It was possible to do so. It's taking a bit more work than I had, so adequate was met with no problem. As far as the HQR: Is it controllable? Yes. Is adequate performance attainable with a tolerable workload? Yes. Is it satisfactory without improvement? No. There are moderately objectionable deficiencies. Adequate performance requires considerable pilot compensation. I think it's probably closer to a 5 than it is to a 4-1/2. More like 4-3/4. Anyway, we'll go with an HQR 5. Basically, what was happening, I got into a PIO in the cyclic, and in order to maintain my position, once I brought it down to 10 feet, I was probably using lateral cyclic up to 1/2 inch to 3/4 inch every 1/2 to 1 second just to maintain my position. I just got into the loop, and I was trying to reduce the severity of my PIO as I got down, but I was working really hard. As a result, I got my heading off to about 7 degrees because I was so intent on watching my cyclic. The collective was another area where I had a difficult time on the rate, or the amount of collective to actually stop. I didn't have a sensation, or a good feeling for the amount of collective to stop a little bit of the rate that I had going. I actually put it in by the seat of the pants. I felt like I put in too much collective, and in reality that was about the right amount. As a result, because I felt like I put in too much, I put in a little bit more, and then I started to climb and descend, and that got into the loop also. All in all I was putting in collective there for a little bit, probably 1/16 to 1/8, may be up to 1/4, collective inputs about every 2 seconds or so at the very bottom. On the ascent, once I got it sort of stabilized I ascended up and adjusted the airspeed. On the heading, it was not too difficult, but again to make my lateral and fore and aft location with the cone, I started to get into a PIO. This time, it was a little bit in to the longitudinal axis. Probably a 1/16, 1/8 longitudinal cyclic every one second or so when I got up towards the top and maintained my position. HQR 5.

As far as the VCRs: It's pretty much the same as it was in the hover. I had fairly good cues because, as soon as I made any kind of an input, I could see the change in the horizon, in the pitch. The roll was what I got into a PIO. I can see that I had a change in roll attitude based on the horizon. Basically, I would say that was about a 2.75 on the pitch attitude, and 2.5 on the roll attitude. The horizontal translational rate: My rates were not building quite as fast as my attitudes were showing, so I didn't have the cues showing I was actually moving laterally or forward as well as I would have liked. That's probably a 3.25 in both axis. In the vertical, my rate was hard to determine on that one, for some reason or another, then the cone was getting larger. That's probably about a 3.25 also. That's the end of comments.

Run 139 (Slalom). Controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I think I'll say yes. I'll say it's fair with mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance. The only thing that I found that I had any difficulty at all was just a little bit behind the loop on it. For the first few I hardly made any inputs. I noticed I needed to add a little bit of collective, and I added a little bit too much, and then I lowered the nose just a tad too much. Other than that, the attitudes were very responsive so I thought it was fairly easy to fly on that one. I go with an HQR 3. The only compensation I had to do was a little bit of forward cyclic at one point to make sure I had my airspeed up when I got down to right at 35, and then I added a little too much so I had to reduce the collective, and add a little bit aft cyclic back in at the very last pole, and I got up to about 42 to 43 knots. All in all, it's fairly easy to fly in that particular configuration, so HQR 3.

The VCRs: My pitch attitude, for preciseness, I thought I had a little more control on it. Either I'm getting used to it a little bit more, or I could see that I got a little bit nose high, and I started slow, so I added a little too much. Again, it was a little bit difficult to figure how much to put in, but I put in input, and then I noticed I was a little too nose low so I corrected for that at the end. All in all, the pitch attitude gave me fairly precise cues so I would say that was about a 2. On the roll attitude, I didn't really notice the roll attitude because all I was using was enough roll to make my turns. As far as being precise on those, I'll just say it's about a 2-1/2 to 3. I'll say 2-1/2 because I really can't say much about it. The horizontal translational rate, longitudinal axis — the pitch attitude gave me a little bit of an idea of where I was as far as my airspeed. My relative rate over the ground, the cues were not there for me, so it's more pitch attitude than anything else. I'm going to have to go ahead and go with a 3.25. The lateral, I wasn't really using the lateral so I won't comment on that. The vertical, I could see, just basically from the white lines, that I was within my parameters. I think I got up to 28 feet at one point. I don't think that I had good cues for precise altitude or vertical translational rate, for real precise control, so that's just fair, about a 3.

Run 140 (Bobup/Down). Okay, desired performance, I didn't meet that 12 seconds. My last two were 13 seconds. My first was 25 seconds. My second was 19 seconds. Maximum overshoot on the bob up, no more than 1/2 square on the hover board. I think I met that. Perhaps on the next and last one I went up a little too high. Maximum overshoot on the bottom no more than 5 feet. Most of them I went probably right at five feet, perhaps a couple of them down below 10 feet, so I know that I had that. I had an overshoot back up at one point of about 19. It was basically one of those artillery shoots, go down below six, up to about three above and then down. So, I met adequate, I didn't meet desired. On two of them I did meet adequate on the bobup/bobdown, but I think if I practiced it earlier, I would have been okay. So, all in all I met adequate, but not the others. Let's go to the HQR: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? No. Moderately objectionable deficiencies. Adequate performance, workload considerable. I think I can go, let's see,

adequate requires extensive ... I think based on these, you could pretty much be around a 5 or a 5-1/2 more than anything else, and that's based on my collective. I also had a little bit of drift, fore and aft, on the cyclic. By and large, I didn't find that I was in a PIO in the loop on the roll axis, or even in the longitudinal axis. I did probably have around a one to two or a 1-1/2 square drift aft. As I descended, I could tell I drifted, so I put in a little fore, and I pretty much came back fairly close to where I stopped. The difficulty was in stopping my rate of climb and my rate of descent. I put in an initial amount of collective, probably 1-1/2 to 2 inches to begin my ascent. Almost immediately I started sneaking it out, so that once my rate was established, then I'd start sneaking it out so I could stop at my desired point. As a result, I was compensating, and I didn't meet my desired performance. On a couple of occasions, I actually went past, and went through the bar on the high side because I didn't decrease it enough. When I had to get back down, I reduced the collective again, probably around 1-1/2 to 2, maybe in that realm. It felt like my rate was building, and then a little bit before my altitude, probably around 18 feet or so, I'd start pulling in my collective, and in every case I put in too much. The amount I put in, although it was too much, I descended through my altitude probably around 6 feet to 7 feet on an occasion. Once the collective took effect I went back up, and shot up to 17 feet, 18 feet, maybe 19 feet one time, and then back down. My target ought to have been 15 feet. I was pumping the collective to hold it to 15 feet until I got fairly stable. I probably made anywhere from 5, 6, to 7 collective inputs, ranging from 2 down to about 1/8 in that 3 second period there. That was the most difficult thing about the task. It was maintaining and getting back in to my altitudes.

On the VCRs: The pitch attitude, I could tell for preciseness on my distance only when I really concentrated on it. It didn't give me super cues so it's probably about a 2.75 because I did notice that I was starting to have a little bit nose high attitude, and that I was going to start to drift. Roll I didn't really notice, so I won't comment on that at all. The longitudinal rate, and the lateral, both of them are probably about a 3. I noticed that I had backed up, but I didn't really notice that I was at a certain rate or anything. My vertical rate, I had a fairly good cue right in front of me to show what it was. The bar, especially when I got down towards the bottom, and saw the happy face. Up at the top, I saw the bar coming in view, those were fairly good cues. Then the middle portion of the cues, actually how fast I was going, and how precise my rates were, it really was not good. All in all, of the whole picture it was probably fair, right around the 2.75 range.

<u>Configuration A</u>

<u>Run 152 (Hover).</u> Desired performance was met. It was a slight bit of continuous wandering after about 40 seconds, I did start to move a little bit, and that got me off. Altitude was easy. Heading was easy. I could remain pretty reasonably stabilized. Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? I'd say yes. I'd say there were some mildly unpleasant deficiencies. Minimal pilot compensation required for desired performance, so HQR 3. I'd say that there is some lateral and a little bit of longitudinal cyclic application once about every 3/4 to a second. They were real small magnitude, 1/32nd of an inch. Just basically pressure and counter pressure more than anything else, and this was all after about 35 seconds pretty much staying almost still. It was fairly easy all over, HQR 3.

The VCR's were pretty much the same. I could get the pitch attitude. I was really trying to concentrate a little bit more on roll attitude. Roll attitude was around a 2-1/2. Pitch attitude, on the real small applications, I wasn't getting the real preciseness on it. I was getting it fairly good on the larger ones. I'd say that was a 3-1/4 on the pitch attitude. Horizontal translational rate. This was probably the worse thing that I had in the longitudinal. I got real small translations that I didn't pick

up very rapidly, and then the rate built, so for preciseness that's probably around a 3-1/2 in the longitudinal. The lateral had a little bit, but I could pretty much see them a little better because of the squares. I could see when I was building any kind of rate so that was probably around 1.75. In the vertical. I didn't really move much vertically, so I can't really give a cue on that.

Run 153 (Vertical Translation). The desired performance, keeping the cone within the lower half of the right window at all times, I did that. Keep target plus or minus 2 feet and heading plus or minus 5 degrees. I've met desired performance. As far as HQR: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I'd say no. There are minor but annoying deficiencies. Desired performance requires moderate pilot compensation so I'd say that's HQR 4, and it's based on the amount of cyclic inputs I had to put in to maintain my position relative to the cone. I was putting in fore and aft cyclic inputs. I'd say 1/16 and 1/8 inputs every one to two seconds. I moved in a little bit too close as I increased [altitude], so I felt that I was having to work a little bit harder in the cyclic realm than should be warranted, as far as being able to just go down. So, HQR 4.

For the VCR's: On pitch attitude, pretty much like the last one, I'd say about a 3-1/2. This was mainly because I didn't have the cues to see that I was actually changing the pitch real small amounts, and I was getting a little bit of forward drift in there, more than I really wanted to, because I had to go forward and aft, forward as I descended and aft as I ascended, so I wasn't getting it as well as I needed to. On the roll, I would say about a 3 overall, because again it's not real good or real precise trying to go in to the cone. Horizontal translational rate: Laterally about fair, 3 because it didn't show the rates I was picking up going in. Horizontal, it's 3.25, it's a little bit worse than that trying to maintain a precise accurate rate. Vertical, I had the cone. It was the only good reference I had. The ball, out right in front of me, really wasn't that effective, so all in all, I'd say that was about a 3.25.

Run 154 (Slalom). I didn't really meet desired performance in that I got sloppy more than anything else. I let the airspeed bleed off just a little bit. It was really fairly easy to fly, and then I caught it, and I got it back up to where I wanted it, and I flew it easily from there. Although I didn't meet the desired, I'm still going to go with the HQR based on meeting desired because I thought that was easy to do. The altitude was no problem. Lateral distance was okay. Adequate was okay. Let's see, on the HQR, Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? I would say yes. There's some mildly unpleasant deficiencies. Minimal pilot compensation was really required for desired performance even though I kind of screwed up on it. I'll give that an HQR 3. The main reason is because I didn't have to do much on the collective. I think I made one collective input at the very beginning, prior to reaching there, because I thought I was starting to descend as I went in from the initial point of IC. I added a little bit of collective, and it was too much so I began to start increasing my airspeed. I also swung out a little too wide as I began the course. I had to correct for it as I went through the course. At one point, as I decreased my collective to reduce it back, I put in just a little bit too much cyclic in it, and I got down to about 34 knots or so. I went actually below 35 knots, so that's why I didn't meet desired at that point. I saw it, and added a little bit, and I descended down a little bit. All in all it was real easy to fly. I had no real problems with it at all. I had only a little bit of fore and aft cyclic application. That was right around the third pole, and that's when I thought that my pitch attitude was off a little bit, so HQR 3 overall.

The VCR's: Pitch attitude was about a 2.75. It was a little bit better. I could see a little bit better attitude for making changes, because I guess I was looking more out at a distance, so that any

type of attitude changes were good. I was picking up real good cues from the horizon, so I could see a little bit better. The roll attitude, I didn't really look at very well, but they were right around the same range, 2.75. The horizontal translational rate, on the lateral axis I didn't look at it, so I won't comment on it. On the longitudinal axis, that's probably the only difficult area of the whole thing. I couldn't get real good cues to see exactly how fast I was going externally, and internally all I had was the indicator, so I'd say about a 3-1/2 on that. On the vertical translational rate, probably not as good as I would have liked, because I descended a little bit. I was getting off probably about 8 feet or so, 10 feet at times, so all in all, I'd say that was about a 3.25, because I just didn't have that good of a vertical rate.

Run 155 (Bobup/Down). Desired performance. The first couple I didn't make it. One was 12-1/2 or 13 [seconds]. The last one I made it at 10, so I think I can meet desired performance fairly well. Maximum overshoot? I didn't have any overshoot. Overshoot on the bottom was less than five. The first time I think it wasn't, but the other ones were all very good, so I didn't really have any difficulty on the whole maneuver. The technique that I used when I started was that I applied probably two inches worth of collective. Everything else remained still as I looked like I was probably five to 10 feet away from the bobup point. Then, I just took out what I already put in, and I kind of went up. By the time I had stabilized, and started the descent, I had been there long enough, two to three seconds, and then I was in my descent, and then I'd load collective about two inches lower. When I got to what I assumed was over 20 feet or so, then I would put in rapid collective application, and that would slow my rate. I'd go down through the overshoot about two or three feet, and then as I started at the very bottom of that, I would decrease my collective, and back to what I thought was my initial position, and I would raise up to about 15 and stop, point one or two feet, and then make any kind of small collective applications after that to adjust. All in all, there were about three or four collective applications on the bottom, and only one at the top, so fairly easy. As far as HQR: Is it controllable? Yes. Is adequate performance attainable with a tolerable pilot workload? Yes Satisfactory without improvement? I'd go ahead and say yes. There were some mildly unpleasant deficiencies, and that was when I had to use the collective. I couldn't just put in one collective input, then stop it, and it would stop it right on that point. I had to use two or three collective applications at the very bottom. When I did that, I got in to just a slight cyclic. I noticed that I would lower my nose a little bit, and then I would have to adjust back having to put in one cyclic application or two. Minimum pilot compensation required for desired performance, so I would say that's HQR 3.

The VCR's: These are pretty much what they've been before. In the pitch attitude, again, probably right around the 3 area. I was looking out at a distance, and that was okay. When I got up to the top, I could see it was off just a little bit, but it wasn't super. It didn't give me that I was showing that I actually had a nose high attitude. It was very small, and I actually translated aft just a little bit, so around a 3. On the pitch attitude, no comment on that. On the roll attitude, no comment on that. Horizontal translational rate on the longitudinal axis about a 3.25. A little less than fair, because I did do a little lateral to the rear, although I could see it once I got down low, up on the top I couldn't see it. At the bottom, it would be a little bit better than fair. At the top, it'd probably be up around a 4 or a 4-1/2. I couldn't see it at all, so it averages out to about 3.25. The lateral translation, no comment on that. The vertical translational rate, pretty much the same as before. A little bit better discerning my rate. I don't know what it was, or if it's just because I'm getting used to it. All I had was the poles and the wires. I started looking through those a little bit more this time, and as they got wider at the bottom, I could see what my rate was. I'd say overall only about a 3.5 on the vertical. In the middle portion it wasn't very good. It wasn't until I got down to the bottom or the top, and then I'm pretty much having to react.

Pilot comment card: Flying technique modified because you're flying a simulator? I don't think my flying technique is modified. The only thing different than I normally do, is I don't worry about the ground as much, because I don't go through it. The only other thing I would say is, you may not be quite as cautious about some of the collective inputs on the bobdowns because you don't want to torque. Some of the aircraft I fly have problems with torque, and if you pull in as rapid as I've been doing here, then it might have a problem with some of the torque. I might be a little bit more aggressive in the simulator. That may be even more aggressive on the poles, because I might cut the corners a little bit, and be real close to the poles on the slalom course, whereas if I was out in the aircraft, I'd make sure I had clearance of that. I'd hate to hit one. If my technique is modified at all, and I don't think it is, it's just that I may be a slight bit more aggressive. Aircraft response? I didn't notice any real changes. I would say in areas of response and crispness, I would say the second one I did was the most crisp. The baseline was next, and the very last one was the least as far as the crispness goes. There wasn't any unusual characteristics. Motion cues affect your control of the rotorcraft, valuable for control? I though they were pretty valuable. I liked the feel in the seat of the pants. I think I made a comment on the second run I had, that I felt like I actually had a little bit of a descent going, and I felt that on the seat of my pants. That might have helped in the visual, giving me more cues internally to my brain, I guess that the visual cues were not helping. Compare this motion system with the other systems flown in this experiment? Well, there were three different motion systems I flew. The second one was kind of a little bit on the jerky side, and I had a tendency to PIO so comparing that one with other ones, it was just a little bit more difficult. This last one is more in tune, like a sludge driver, like I am. It was easier to control, and probably the preciseness and the aggressiveness, you weren't as quick as the other ones. In the baseline, in comparison with that, it's like what I said about the first one. The baseline was in the middle, this one is a little bit slower, and the second one was quicker. Fixed base was the one that got me the most nauseous than any thing else. Out of the four, it was definitely the worst. I liked the motion, and it gave me some different leads, and stuff to help me to go along with the visual cues. The motion and the visual cues seem consistent? I thought they seemed fairly consistent, and I didn't notice anything different. Unusual, conflicting, uncomfortable, visual motion cues? Fixed base is uncomfortable. Looking out, you'd think you were in a turn, and your body says no. It's just a little conflicting, and it's hard adjusting to that. On occasion, if I got into a PIO from the outside in any of the environments, then I would get a little nauseous or kind of a queasy feeling, and that goes along with number seven. That was basically in the bobup/bobdown. It was the worst task of those. Visual scene? The only thing is that it would have some more vertical obstructions out there, and that would probably aid in some of the attitude problems that may be in the lateral and the longitudinal drift.

G. PILOT Mc

Baseline Configuration (Fixed Base)

Run 114 (Hover). Desired performance — keep the cone within the lower half of the window. I did. It wasn't reasonably stabilized. At times it was starting to drift away. It'd be stable for 10-15 seconds then I'd move off so I didn't meet that requirement. Altitude was within 2 feet. The heading was within plus or minus 5. Not as good as with the motion. I think that I am at desired performance. It's controllable. I did get adequate performance. It's not satisfactory without improvement. The deficiencies I found, primarily ability to maintain a good attitude, roll and pitch attitude, was kind of difficult. It was very hard to tell if you had a big change or a little change. I would give it an HQR of 4. I was doing a lot of compensation as far as fore and aft and lateral cyclic inputs. About a standard two inputs per second in different directions.

As far as VCRs: Pitch attitude was not very good. Not as good as fair, I'd give that a 3-1/2. Roll attitude was a little bit better, I'd give it probably a 3-1/4. Horizontal translational rate, if I took my attention off the cone and looked outside it was okay, but sort of crept away without seeing it outside too well. If you started going fast and made a big correction you could really tell you were moving so I would give it another 3-1/2. Vertical translational rate, I didn't notice much change in altitude at all so I couldn't give it a good fair rating on that one. I got off maybe one or two feet. Noticed it, though, so I'd have to say on this level it's about a 3.

Run 115 (Vertical Translation). Desired performance is to keep the cones on the lower half of the right window, and I did. Get your target altitude plus or minus 2 feet, I did. The heading plus or minus 5 feet, I didn't, because my attention was distracted by having problems in controlling the roll attitude during the up and down motions. A combination of that, and being concentrated on the cone so I don't think that was a problem with the configuration. HQR-wise, it's controllable during the task. You do get adequate or better performance except for the heading, but I think that was me more than the situation. Not satisfactory without improvement, that's for sure. I will give it an HQR of 5. The reason for that is when you couple the maneuver up and down, moving laterally to keep the cone in the same relative position, it's very easy to have a problem with roll attitude based on the fact that it's hard to judge what your attitude is until you've gone beyond what you need, and then it's obvious you went too far. Consequently you then go the other direction to compensate for it, and again go too far before you get the cue, but you got what you wanted so you're getting some result. I was working too hard in the lateral. Overcompensated, probably overshot about three or four times when I was trying to get just a stable position I desired.

As far as visual cue ratings: Pitch attitude, I didn't have a lot of play in this one. It wasn't all that good, either. What little bit of movement I had, I'll give it a fair 3. I didn't make a lot of corrections that way. Roll attitude, I'm going to have to say it's closer to 4. No real precision at all so you had to make smaller corrections. If you did more than that, you're overcorrecting. Horizontal translational rate, I had a little bit of problems. I could not be real aggressive, otherwise I'd get too far away, and faster than I thought I was going. Consequently, I would say it's not very good for that particular task. I'll give it a 3-1/2. Vertical translational rates, without the rad alt, I'd say I didn't have a lot of good cues. I made very limited corrections. I would give it a 3-1/2.

Run 116 (Pirouette). Desired performance, to keep the red and yellow pads on the instrument panel. It was under the instrument panel, but I didn't meet the desired performance I had before. For parameters, I've been using the pads, drifting in a little bit then drifting back, a little further than I was supposed to be, but it's not very far out. I maintained altitude pretty good that time. I got a little high, but I never got off of 5 feet. Heading on the nose, the aircraft pointed to the center. I kept it pointed to the center pretty well, and I did meet it within 45 seconds. Other than moving in and out of my red and yellow boundary, I did okay. I'd say I almost got desired performance. HQR for this task: It's controllable. You can get adequate performance with tolerable workload. It's not satisfactory without improvement. There are some deficiencies in the pitch attitude, and cues. It's very hard to make small pitch corrections to maintain your distance away from the pirouette tower as far as being on the red and yellow line. There was a lot of concentration and work for that, and constant movement of the cyclic fore and aft just to find out where my pitch attitude was. You don't get a very good cue for small changes. I'm going to give it a 4-1/2.

Visual cue ratings: Pitch attitude, I'm going to leave it the same as I have before, as a 4. Roll attitude is pretty good because you can hold a constant roll attitude until you roll out, and then once you roll out there's not a big problem to know what your attitude is. Did overshoot on the last one

a little bit. I didn't make it very aggressive so I'd give it a 3. Horizontal translational rate laterally, as I was going right and left around the tower, it was good. A good sensation that it was constant speed, and what not. I didn't feel any problems with that. I didn't make much corrections at all except for trying to stop. I didn't do very good on the stopping so I will give it a fair, 3. Trying to judge when to stop was my biggest problem. Vertical translational rate, I picked up a few more cues that time that I was climbing and descending, but they were not that good so I'll give them a fair, 3.

Run 117 (Slalom). Desired performance was to go through it 35 knots without slowing down, going to a maximum of 43. I was fairly stable around 35. I saw myself decelerate to 30 knots when I was concentrating on the first two towers during the roll maneuver and I didn't notice pitch attitude change. I just slowed down to 30 so I didn't get the desired performance there. Lateral distance from the poles, I was within desired parameters, and altitude was pretty good that time, definitely within plus or minus 15. I didn't get desired performance on the airspeed during the first two aggressive turns. I think that was based on the fact of the maneuver. HQR-wise, it's controllable. I did get adequate performance. Is it satisfactory without improvement? No. The deficiency again is the lack of pitch attitude cues. The fact that when you're aggressive in the roll axis your cues as far as your pitch attitude may or may not have changed. The altitude didn't change any. I'm quite sure it was the roll. I raised the nose up during the maneuver so I think something that needs to be compensated there by the pilot. You've got to look inside because you can't tell outside. I didn't get desired performance, I'll give this maneuver a 4-1/2 also, primarily for the problem of maintaining airspeed in the aggressive part of the course.

Visual cue rating scale: Pitch attitude, I'm going to go down to a solid 4. You can't make precise changes. Roll attitude was good. I would say I knew when I made an aggressive change, and when to stop getting around the pillars. I could be quite aggressive as far as the beginning of the course. Precision was good, I'm going to give it a 2. Horizontal translational rate, since I was aggressive, stayed within three, I'm going to say that it was quite good for this particular task, 2-1/2. Vertical translational rate, the altitude stayed quite good, I didn't have any trouble with that. I can't really rate this one since there were not any changes made at all. Just say it's fair 3.

Run 118 (Bobup/Down). I did each one in 12 seconds or less. The overshoot on the bob up, no more than 1/2 a square on the hover board, I believe I made that requirement also. And overshoot on the bobdown no more than 5 feet, and this time I met that requirement. I got desired performance this time, amazingly enough. I have to make a quick aside here, that maneuver makes me feel queasy in the stomach. The aircraft is controllable in this configuration. You can get adequate performance. Is it satisfactory without improvement? Definitely not. Oh, wow, what rating to give it this time? I did get desired performance, but with more than minor deficiencies to me. What are the deficiencies? The deficiencies are cues in terms of vertical translation rate. Once you start going, you have a hard time to determine that you have stopped moving. I had to compensate quite a bit, especially on the bobdown by getting the rate started. Consequently, taking out half the input I gave it to start the rate down, and then coming in, crosschecking my altitude, and then sneaking in enough power to stop it. You really kind of work hard on that. I'm going to give it a 4-1/2 primarily for that reason. I didn't drift fore and aft or left and right as much as I did in the past. There was some drift that's hardly noticeable while you're doing the up and down maneuver. You don't realize it until you either stabilize at the top or at the bottom that you've moved. It seems like every time I came down, I backed up, and I didn't notice I had changed the pitch attitude that much.

Visual cue ratings: Just based on my last comment, you don't have very good pitch attitude change indications so you can't make very aggressive changes in pitch attitude. You can't even see the small ones that you have made, I give it a 4. As far as the roll attitude, it didn't come in to play this time. I don't think I should rate it. Horizontal translational rate, as far as knowing that you are moving forward, once you get about halfway up, you don't have any cues as far as fore and aft movement until you start seeing the board, and you can start judging that you're getting closer to the board so the cues aren't very good. I'll give it a 3-1/2. Vertical translational rate, I had the biggest problem with knowing how fast I was, and when I made a change to slow down realizing that the change was taking effect so it wasn't very good. I wasn't aggressive especially on coming up and down. I gave a control input to get started, and then took it out just to see what was going to happen so I could be less aggressive there. I would say it's fair, probably a 3-1/2.

Run 119 (Dash/Quickstop). Desired performance was to stabilize past the last pole before the red and yellow line. I did. I had a lot of overshoots, but I met the desired performance. Maintaining altitude within plus or minus 15 feet, I think the max I was off was 10 feet high so I think I was okay there. I met desired performance for this particular maneuver. HQR Scale: It was controllable, adequate performance was attainable with reasonable workload. It's not satisfactory without improvement. The deficiencies I noted: You don't get a good clue of vertical rate of motion unless you're going up and down until you've got quite a rate developing. Sensation of moving forward was okay, however, it's hunting and pecking the pitch attitude. It was hard to maintain a constant one. So, I finally said, quit moving it, and left it where it had fallen out at. It felt normal, which it was somewhere about 4 degrees nose low. I'd start the maneuver going 10 degrees nose low, but it's hard to hold it down. Consequently, I only got the 60 knots just a split second before the yellow line to start the decel. Once you start the decel, the pitch attitude is very hard to judge if you went enough or too much. I overshot trying to hunt and peck for a good pitch attitude. It required quite a bit of cyclic input fore and aft during the decel portion. I'm going to give it a 4-1/2 again. The deficiency is in the pitch axis. One other thing that I noted, I didn't note that I had drifted off to the left which is not part of the maneuver or criteria in desired performance. I drifted left without realizing it at the beginning until I'd gone about a square and a half off the left. I had lack of some cues there.

As far as the VCR ratings, pitch attitude is 4. Roll attitude — concentrating so hard on the other one, I'd say it was fair. I didn't notice that I was drifting left, I had some left input in it at the beginning. That was only a small correction. As far as the horizontal translational rate, it's very hard outside to tell that you're continually accelerating. The only good gauge of acceleration is the airspeed indicator. I think that's one of the reasons it's hard to get your pitch attitude where you want it to be because you're not real sure if you're still going faster or not. I'm going to say that's not quite good, I'm going to give it a 3-1/2. Won't do it laterally because it didn't really come into play that much. Vertical translational rate, I already said, it's hard to determine when you start moving; once a rate develops it becomes more obvious. Can't tell you how fast I was going when I noticed it. The cues were small, limited corrections are not very good, I want to give it a 3-1/2.

Run 120 (Sidestep). Desired performance was to stay aligned with the red and green stripes. I must have had 20 feet, I was keeping a dash over it.
I went forward a little bit. Altitude plus or minus 10 feet. I think I just barely made it. Heading within plus or minus 10 degrees, I don't think was a big factor. I think I got desired performance, just barely got it in two areas, the longitudinal position and altitude. Altitude really went 13 feet or so going left. The aircraft is controllable, you can get adequate performance. We got pretty high workload. Is it satisfactory without improvement? No. Deficiencies warrant a lot of improvement.

Maintaining your altitude is very hard to do. I couldn't quite judge that I was climbing or ascending as much to the right. I had a problem going to the left while stopping. I didn't have any sensation that I was descending like I was. I didn't notice until I was crosschecking the instruments. I got desired performance barely, but I'm going to give it a 5 for this task because of it being very hard to judge your altitude, maintaining altitude especially. I also had a little bit of trouble today rolling out. Once I got established in a good aggressive move I misjudged the rollout, and overshot a little bit, maybe one time so I wasn't very aggressive to do it. I'll still give it a 5.

Visual cue ratings: Attitude — pitch attitude hasn't improved any. It's very hard to tell that you're backing up or moving forward. Small changes you can't really notice, so I'll still give that a 4. Roll attitude — during the changeover it's very hard to determine your roll attitude. It seems to be a little bit sluggish in response if that's the correct word. It's hard to judge what your roll attitude is during the stopping portion of the maneuver, so I wasn't as aggressive as I could have been, but it wasn't real bad, I'll give it a 3-1/4 if that's acceptable. Horizontal translational rate, once you get established, it's hard to determine if you're speeding up or slowing down. I almost got the sensation that I was slowing down going to the right, but then I overshot a little bit so I wasn't sure. It's not very good cues for translation. I want to give it a 3-1/2. Longitudinal translation didn't come into play too much that time. It did move a little bit off the line. I didn't get a very good cue for it either. I give that about a 3-1/2 also. Vertical translational rate was not good at all. It's not poor because you can make corrections, the rate gets high before you really notice it. I'm going to give it a 4.

Pilot comment card: I modified my flying technique. Basically I don't get any cues at all from the extra sensations I have flying this way. Obviously I compensate by really looking around a lot more, and cross checking the instruments, and the outside scene. The aircraft response? It appears slightly sluggish when you're doing it this way. I don't know why. Unusual characteristics? The only thing unusual is the small attitude changes. You just don't get any feedback. You don't get any aircraft response. You don't see a response for small stuff. There were no motion cues unless you're talking just about visual cues. Motion helps me keep my perspective on what the aircraft was doing a little better. Visual cues seemed consistent, we already talked about the little degradation in the scene, but there were no inconsistencies that I really noticed. I guess the inconsistencies that I would say in terms of up and down translation, vertical translation, the visual cues are not there for small slow rates. Once they get large and fast then you get some cues, so there's a little inconsistency there. The uncomfortable visual cue to me was any time you did something real aggressive in the vertical axis. I felt uncomfortable in doing the bobups and bobdowns. They were hard to do aggressively based on the fact that you get up there, and the only sensation you have is the up and down motion of the hover board or the happy face at the bottom. The nausea occurred, we've already talked about that on the hover bob up, and a little bit there at the end of the quickstop. I didn't feel so good there either. They only last a couple of minutes because we went to IC. Deficiencies in the visual scene? No. Lack of cues in the vertical motion is a big deficiency. The other deficiency I would say would be the lack of translation horizontally. The lack of sense of increase and decrease in speed is very hard to determine from the outside cues.

<u>**Baseline Configuration**</u>

<u>Run 144 (Hover).</u> At the end the cone wasn't reasonably stabilized, it does wander quite a bit. The altitude was no problem, within plus or minus 2 [feet], and heading was no problem. I didn't meet desired performance because the cone continuously wanders. HQR on this task: It's controllable. Is adequate performance attainable with tolerable pilot workload? Yes. Is it

satisfactory without improvement? I'm going to say no. There are minor but annoying deficiencies. I had desired performance, other than the cone wandering a little bit. I think we've got to give it a HQR 4. The problem is continuous small corrections in the lateral and longitudinal cyclic required to maintain your position. I'd say one or two in both directions every second to keep the cone from wandering a lot.

As far as visual cue scale: The pitch attitude cue, I would give it a fair. You can make small corrections in pitch, but the precision is not real good, so I'd give it a 3. As far as lateral, I'd say it's also fair, a 3. You can't make very large corrections with any confidence, and you don't rack up any good precise control over the lateral controls. Horizontal translational rate: Since I wasn't moving too much, it's kind of hard to judge. You did know when you were moving, but you had to constantly swivel your head, so I would have to say it was fair, a 3 also. Vertical translational rate: It did come in to play somewhere, but I won't rate it.

Run 145 (Vertical Translation). Desired performance was to keep the cone with in the lower half of the right window. I did. To achieve target altitude within plus or minus 2 feet. I did. Maintain heading plus or minus 5. I did, so I met all the desired performance requirements. HQR: It's controllable. Is adequate performance attained with a tolerable pilot workload? Yes. Is it satisfactory without improvement? Gosh, I'm at a crossroads here. I want to give it a 3-1/2, and I know I can't, so I'm going to say no. There's some very minor deficiencies, so I'll have to give it an HQR 4. The reason I give it an HQR 4, it seems like it's very difficult to detect and maintain your position when you're moving up and down unless you do it really slow. You can't keep the cone in the lower portion of the window and combine the heave with a lateral translation.

As far as visual cue rating: Pitch attitude, again, I'll give it a 3 for fair. You can make small corrections. They're not very precise corrections. And the same with the roll attitude, I'll also give it a 3. Horizontal translational rate: I'm going to give it a 4, mainly because you could only make really small corrections as you're moving up and down. You can't really be precise at all. It's very hard to keep the cone at the bottom when you do aggressive maneuvering so that's a very poor cue. Vertical translational rate: I'll give that a 3-1/2, somewhere between fair and poor. You make very small corrections, and you're not very precise. The top or the bottom, just before you start, you can make a one foot change pretty easily, but you have to rely on the gauge instead of looking outside. You don't have real good cues outside. It's very hard to tell any motion. Moving up and down, it's hard to tell any lateral motion at all.

Runs 146-148 (Slalom). Desired performance was to keep the maximum lateral distance from the poles less than 3 squares. I believe I met that requirement. Maintain airspeed within plus 8 and minus 0 knots. I think I lost about a knot or two, so I didn't quite make it there. Maintain altitude within plus or minus 15 feet. I met it easily. I could have met the airspeed requirement if I hadn't tried to keep the altitude within 10 feet, so I think desired performance was attained. Now, HQR for this one: It was definitely controllable. Is adequate performance attainable with tolerable pilot workload? Yes it is. Is it satisfactory without improvement? I would say, no. Minor but annoying deficiencies. It's very hard to detect any airspeed changes. You're constantly having to crosscheck, both in and out, and make small corrections on the cyclic for your airspeed during the turns around the pylons. It requires moderate pilot compensation, so I give that a 4.

Visual cue ratings: Pitch attitude for this particular maneuver, I give it a 4. You could only make real small corrections because you don't have any good indications what's happening outside the aircraft. When you combine it with roll attitude, you get real good feedback on roll attitude. I'll

give it 2-3/4 for the roll attitude. Horizontal translational rate: I get a pretty good sensation that it's moving laterally during the turns around the poles as you go on across from side to side. You can make pretty good corrections. I'll give it 2-3/4 also for that. Vertical translational rate: You don't get very good cues, especially when you line it with the other maneuvers. When you're making a big bank to go around the pylons, you can't really tell what your altitude is doing. You get a slight cue, then you have to check inside to confirm it, so you make small corrections next. I'll give it 3-1/2.

Run 149 (Bobup/Down). Desired performance was to do each bobup and bobdown within 12 seconds or less. I did. Maximum overshoot on the bobup about 5 or 6 feet. I think I met that requirement easily. Overshoot on the bobdown no more than 5 feet. I never went below 10 feet, I stayed pretty close to 15 feet each time, so I met that requirement also. As far as HQR: It is controllable. Adequate performance is attainable with a tolerable workload. Is it satisfactory without improvement. Well, I have to give this a 3. There are some mildly unpleasant deficiencies. There's very minimal pilot compensation required for desired performance this particular run through. The compensation required is in the heave motion as you kind of make two or three inputs, and use the collective when you're approaching your top and bottom positions, about three adjustments to get stabilized out. There's not very much required, and to hold position in both places wasn't very difficult this time, so I give it a 3.

VCR ratings: Attitude cues. Pitch attitude: I didn't have very much change in pitch attitude at all, if any, so I didn't notice any. I'm not going to rate that if that is okay. Roll attitude: I'd have to give it a 3-1/2 for roll attitude. The only reason I would bring that up, I noticed on at least two out of three of them I had some roll. I slid to the left as I came up, and I was stabilized when I started, so you don't notice there's a little bit of roll attitude change as you go up, so you've got a real good cue. Horizontal translational rate: I didn't have much motion fore or aft and left and right, except for a little bit to the left there going up or down. I don't think it's much better than fair, I'll give it a 3. Vertical translational rate: I got pretty good cues there this time. It's not quite good, but it's not bad, I'll give it a 2-1/2. Somewhere in between the limited and aggressive corrections on the collective in the heave motion.

Pilot comment card: I modified my technique flying a simulator just a little bit. You've got to fly a little differently by: (1) where you're looking as far as for your cues. (2) You've got to be looking for three or four different things outside at one time to try to get a cue for motion. That's about it. Aircraft response? It was not quite crisp, but it was pretty quick. It didn't have any unusual characteristics on it. The motion cues were pretty valuable for control. Motion and visual cues did seem to be consistent. The only unusual thing was when I was flying the slalom, and I came around to do the hover board the first time for practice. I felt like I was backing up looking outside. I was getting indication of 30 knots airspeed so I wasn't quite sure what was going on there. That was just when I was coming around from the first slalom run to do the hover board. I never did feel sick at all, and no major deficiencies to discuss in the visual scene.

Configuration A

Run 157 (Hover). Desired performance was met easily. I kept the cone within the lower half of the window. It was pretty stabilized. Maintained altitude within two feet. Heading within five degrees very easily. HQR: The aircraft is controllable. Is adequate performance attainable with tolerable pilot workload? Yes, very easily. Is it satisfactory without improvement? I'm going to say yes. I have to give it an HQR 3. It's very mild deficiencies. Minimal compensation required for desired performance, it almost hovers by itself. You only have to compensate for drift once every

five or six seconds as far as fore/aft drift. You can make small inputs, and get back to where you want to be very easily.

VCRs: I want to give it a 2-1/2 for pitch attitude. I was between aggressive and limited corrections in pitch. It's better than what I've seen it before. Roll attitude, I'll give it also 2-1/2. It felt pretty comfortable making corrections to get me back where I wanted to. I didn't have to make more than one input to get back to where I wanted to in either case. Horizontal translational rate: The cues were pretty good. You could note real small drift laterally just by looking outside. You could see things changing pretty good this time, and I could correct for it. I give it 2-1/2. Vertical translational rate: I didn't go up or down at all, so I'm not going to rate that one for this particular task.

Run 158 (Vertical Translation). I met the desired performance. I kept the cone in the lower half of the window. I met the altitude within two feet. I maintained heading within 5 degrees. I got off slightly at the bottom because I started concentrating too hard on the cone, but it was no problem as far as noticing that I was getting off. HQR: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I'm going to say yes. HQR 3. The only deficiency I have, as far as compensation, is that you have to compensate pitch a little bit. A couple inputs, every two to three seconds, just to keep from accelerating forward and aft more than you wanted to. When you're moving all the way from the cone, changing your altitude, it was pretty good.

As far as the VCRs: Pitch attitude: I'll give it a 2-1/2 again for cues. It's pretty aggressive, and my cues in roll attitude are the same. I'll give it a 2-1/2. This maneuver I did a lot more aggressively, quicker than the last time, because the aircraft feels better. Horizontal translational rate is good. Good cues, and I'll give it 2-1/2 because I can maintain the cone in the window, and moving up and out is pretty good. The vertical translational rate: I'm going to give it a 3 because I had to limit my corrections on the collective when I was trying to stabilize out at the altitudes.

General comment: The motion and the visual system seem to be more in line with each other than before. The aircraft seems to be more damped, that seems to be a good word for it.

Run 159 (Slalom). Desired performance was to maintain less than three squares away from the poles. I did. Airspeed plus 8/minus 0. I had a plus 5. Right at the end I got about a plus 6, but I did meet that requirement. Altitude within plus or minus 15 feet was easily met, I think I was off maybe about 6 feet on the high, 2 feet on the low. Let's see, handling qualities rating. It's controllable. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? That's a good one to rate there. I want to give it a 3 plus. I don't know if I can do that, but the only deficiency I've found is that it's hard to keep from making cyclic inputs, or changing your pitch attitude when you're making the roll inputs to go around the pylons. I kind of felt myself lowering the nose while I was doing it. I didn't get very good cues, you had to kind of compensate for that, and make small aft cyclic inputs, one each second just to keep it from speeding up on you.

Visual cues: The pitch attitude, I'll have to make it a fair this time, because of those cyclic inputs I had to make. A three. Roll attitude: I would say that you could be aggressive and precise very easily. I'll give it a 2-1/2 again. No, give it 2-1/4 that time for the roll attitude. Horizontal translational rate I would say was good, I'll give it a 2. Vertical translational rate sort of matched by

the other rates. You really don't see going up and down as much, but you still get a better idea than before, so I'm going to give that a 3.

Run 160 (Bobup/Down). Desired performance was to do each one in 12 seconds or less. I did. Maximum overshoot on the bobup, plus or minus 6 feet. I overshot one of my four by about 6 feet, but I think I met the desired performance. Overshoot on the bob down no more than 5 feet? I didn't have any problem with that. I think I was probably between 13 and 18 feet for the bob downs so I met the desired performance. Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? I have to say no this time. Desired performance requires moderate compensation of the pilot. It's a 4 minus if I can give it that. The only deficiency I have is again in heave. Control of the collective requires a couple inputs to level off at the desired altitude. You're moving up, and then you've got to put it down and back up a little bit, to make quick adjustments, two or three. It's more noticeable at the top than it is at the bottom. I think with the bottom, I've got a good cue with the horizon there as to what 15 feet is. That's really kind of difficult with the top to tell if you're even with the boards, and trying to do it as fast as we're doing it in 12 seconds. I would give it a 4.

Visual cue ratings: Pitch attitude cues. You don't notice much change pitch or roll this time, so I'm not going to rate it. Obviously they're okay because I didn't start wandering around a lot. The translational horizontal rate I'm not going to rate, either, because I didn't really see much translation. Vertical translational rate. I might give it a 3 because you can't be real precise on your points to start and stop your descents at. The stop one is probably the biggest problem. You kind of limit your collective inputs, and you don't get very precise especially at the top, at the bottom, even when I was 3 feet off my 15 feet.

Configuration N

Run 162 (Hover). Desired performance was to keep the cone in the lower half of the window, which was accomplished. The cone was reasonably stabilized. It was wandering a little bit. Altitude plus or minus 2 feet; I was right at the limits of the plus 2 feet. Heading plus or minus 5. Just had plus or minus one or two, so it was okay. I met desired performance. The aircraft was controllable. Is adequate performance attainable with a tolerable pilot workload? Yes. Satisfactory without improvement? I'm going to say no. Minor but annoying deficiencies. Desired performance requires moderate pilot compensation, so I'm going to give it a 4. You have to catch any translational movements quickly, and make small inputs, particularly fore and aft, one or two per second once she starts, to stop it and then get it back where you want. You then have to let it go and see what's going to happen next. I had a tendency to PIO a little bit in small inputs both laterally and longitudinally in the cyclic. Towards the end of the maneuver I finally managed to convince myself if I quit moving so much, I'd be more stable, and I was. Any small movement with the cyclic, it seems to start you going, and you always appear to be moving. It's very hard not to wander around.

Visual cue ratings: Pitch attitude cues: I had to make pretty limited corrections, so I'm going to give it a 3. The same for roll attitude. No, give them both 3-1/4, that is what I would like to do. Horizontal translational rate, I'm going to say it's a 3-1/2. I don't know, I always got the impression that I was constantly translating. I never did feel comfortable with the fact that it was telling me that I was stable. As far as the vertical translational rate, I had trouble this time maintaining my altitude. I'd run it up and down around 2 feet all the time, so I'm going to give that a 3-1/2.

Run 163 (Vertical Translation). Desired performance was met. I kept the cone in the lower half of the window. I achieved the target altitudes plus or minus 2 feet. I maintained heading plus or minus 5 degrees, but I had a little more difficulty requiring more pedal inputs. I was off probably to the limit at one time. It is controllable. Adequate performance was attainable. It's not satisfactory without improvement. I will give it a 4 for HQR. The pilot compensation required to do that is continual cyclic inputs, fore and aft longitudinal inputs to maintain your position. It's very hard to pick up on small pitch attitude changes there. I'm constantly making corrections of about 1/4 inputs fore and aft every second while I'm moving up and down trying to be stable. Lateral inputs are required, also, as you try to move away from the cone as you're climbing up, and closer to the cone when you're descending. You can't be precise in where you put the cyclic to get to where you want to start translating to, away from, or towards the cone. You have to kind of hunt and peck for an attitude that will get there. You've got to use 1/4 inputs to get the desired effect similar to the pitch attitude ones.

As far as visual cue ratings: You kind of limit your corrections, and you're not very precise. I'll give it a 3-1/2 again for pitch and roll attitude both. Horizontal translational rate: I had a hard time picking up on the cues this time. I give it 3.75. Vertical translational rate: It's not quite as good as it was. It was real hard to determine that I was going up as fast as I was going, or as slow as I was going, so I did it very slow. I didn't have good cues. I'll give it 3-1/4 on that one. Overall, the aircraft, you can't seem to be as precise with your control inputs right now.

Runs 164-166 (Slalom). Desired performance was to stay within 3 squares of the poles. I met that with a little difficulty. Airspeed plus 8/minus 0 knots, I did not meet. I didn't meet the airspeed, probably because I was tired from doing it three times in a row. The second one was better, and I'll base it on that. Altitude plus or minus 15 feet? I didn't meet that. I wandered quite a bit. HQR for this task: It's controllable. You can achieve adequate performance easily enough. Is it satisfactory without improvement? No. I want to give it an HQR 4-1/2. It's very hard to notice your pitch attitude changes, so you have to make cross reference to airspeed, and make continuous cyclic inputs to keep your airspeed from getting too slow this time. I still don't have a problem keeping it from getting too fast, so I couldn't tell during the roll that I was raising the nose, or it was coming up, so I had to keep pushing the nose over. Also in the roll, it's very difficult to get a precise attitude change to go around the pole. If you looked, I think I was probably going from the start out at the very beginning of the poles. It's hard to be very aggressive without over controlling it and overshooting your desired bank angle with corresponding cyclic inputs. You're not just making a crisp input and holding it. You're making an input, and modifying it a little bit, and then making the input go in the other direction. As far as altitude, it's kind of hard to maintain altitude this time, but I didn't mess with the collective that much, so 4 1/2 is what I give it.

Visual cue ratings: Pitch attitude cues: I'm going to give it 3-1/2. You really couldn't notice the changes there, not as good as I like. My roll attitude, I'll give it a 3 because you can't be real precise, and you've got to limit how much you put in. Horizontal translational rate, I'm going to give it a 3 also. It's hard to tell how fast you're moving around the pole when you're translating sideways as you go down the course, so you have to be quick on when you decide to start the bank going the other direction. I didn't get a very good cue on that. It seemed to be all, a certain time, at the bank going the other way. The vertical translational rate: I'm going to give that a 4. Even with the white portion of the cones, while I'm doing the pylons trying to stay midway between them, which is about 20 feet, you really don't notice if you're climbing or descending until after you climbed or descended a good, I'd say, 7 feet, especially during the aggressive portion of the task.

Runs 167 and 168 (Bobup/Down). Desired performance was to complete each one in no more than 12 seconds. I don't think I met it on the second one. The first and last one I did. Maximum overshoot no more than 1/2 a square on the hover board. I think I overshot that on the first one, but I met the requirements on the other. And overshoot on the bottom no more than 5 feet. I think I just met that one. Overall, I would say I met desired performance except for each of the three requirements on three different maneuvers, so I think I made it. Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? I'm going to say no. HQR 5. To get adequate performance, even though I got desired performance, you really have to work hard on this particular one, or maybe I'm just tired. Let's change that HQR to a 4-1/2. It's hard to tell when it's time to stop going up, and you have to kind of hunt and peck again with the collective to stop at the right position. Going up, I made an input to stop. I'd lower the collective a little bit, and that would stop me, but then I had to make more and more input to get finalized down in a stable altitude. Coming down it was very difficult this time to stabilize at the bottom unless I slowed down the rate, and that increased my overall time on the second one. On the third one when I tried to go down as fast as I went up, I dropped down to about 4 feet below my target altitude. It took a couple of times of bouncing up and down to get settled out.

As far as visual cues go: Pitch attitude: I didn't notice much change in pitch attitude, so I'm not going to rate that, or roll attitude either. I was concentrating too much on going up and down. Horizontal translational rate: I did notice that I moved a little bit, both forward and sideways. Overall, I didn't try to make corrections, so I give it a 3-1/2. The vertical translational rate: I would give that a 3-1/2. For the amount of input I put in, it was hard to judge what kind of aircraft response I would get. Looking outside, you didn't get any response to your input until after you waited a noticeable delay. I couldn't be as aggressive as I wanted to be, so I give it a 3-1/2. I don't want to say totally engrossed with getting in to the right altitude, but pretty close.

Pilot comment card: My flying technique? I wasn't modified as much as I thought this morning. I guess I got used to being in the simulator, in the box again. I didn't use the pedals much at all for this particular flight, I don't know why. Aircraft response? On the first one this afternoon, I thought it was crisp, and I could be very precise on what I wanted it to do. The second one didn't seem to be as stable as the first one. It wasn't as crisp, but it wasn't sluggish. It would move, but it wasn't as good as the first one. Motion cues? They were good for the control of the aircraft for both the scenarios. This motion system is the same as the other systems, I guess. I don't know, the second one I did, overall, felt more like flying than any of the others. The second one, the motion and visual cues seemed to be the most consistent between my inputs, and the aircraft response, and what happened on the outside, using visual reference cues to attitude, than the last one did. I didn't have any uncomfortable motion cues. I didn't get a feeling of discomfort at all. I don't know, but I thought that there was kind of a delay, maybe I'm just tired, in the visual response in this last simulation. I don't know why I get that impression, but I'd make small pitch attitude changes, and I'd see the texture of the horizon change well after I made the input. You'd go from a dark to a lighter dark, or a different shade of grey, and you could notice it. There was some delay. I don't know why.

H. PILOT H

Configuration A (Fixed Base)

Run 301 (Hover). The main problem with that is the continuous low frequency drifting which we always seem to have with rate systems. Altitude control was no problem, and heading control was no problem. We certainly had a problem keeping the cones stable in the window. The hover cues are just much different than in a real helicopter where you can look down at something and stop the thing over the point. Here it's necessary to look out at the horizon, and back down, and a lot of division of attention. Pilot rating: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Is it satisfactory without improvement? No. Deficiencies warrant improvement. I find the continuous drifting objectionable. A couple of times the cone actually left the window, and towards the end I was actually able to keep it in there with a very high level of attention. I think it's at least moderately objectionable, and performance only adequate because of the continuous drifting of the cone. HQR 5.

Run 302 (Vertical Landing). This task really emphasizes the problem of trying to stabilize the hover. Again, it's characterized by these large, low frequency motions. The lower I get, the worse it gets. Getting down close really magnifies the problem. I also noticed that my division of attention required to hold heading, and look at altitude, caused far more oscillations in X and Y, which is an indication of the extreme attention required to control the X and Y position. Any large attitude changes in X and Y result in a disaster because you just can't recover. There's not enough cues there to stop the motion, and bring it back to nominal. Pilot decision: Is it controllable? Yes. Is adequate performance attainable with a tolerable workload? Yes. Is it satisfactory without improvement? No. Here, I believe we're at the bottom of Level 2. It's very objectionable, but tolerable. If I can keep the cone in there, at least within the window, even though it's moving all around, it's definitely adequate, but very objectionable, and always on the edge of control. Pilot compensation is extensive so the HQR is 6.

Run 303 (Pirouette). The primary problem in doing the pirouette is that it takes too long to perceive the fact that I drift in and out of the circle, and so by the time I see it, it's already built up to a pretty large value so therefore I have to use a large attitude to stop it. There are extreme attitude excursions going around there, plus and minus as much as 5 or 6 degrees in each direction, which is very unacceptable. That should have never been that way. As a result, I always feel behind the action. It's always trying to make corrections from big errors. The whole idea in doing a task like this is to keep the errors small, and make little corrections for little errors, and that's not possible because they build before you can see them. Okay, pilot rating: Is it controllable? Yes. Is adequate performance attainable with a tolerable workload? Yes. Barely, I might add. Satisfactory without improvement? No. I believe we're down here between moderately and very objectionable. I think the compensation is between considerable and extensive. Consequently the pilot rating is 5-1/2. The primary thing there is the inability to perceive the drift rate until too late, and the corresponding very large attitudes required to stay within adequate performance.

Run 304 (Slalom). Not too much to say about that. It actually went fairly well. It did require quite a bit of division of attention to hold airspeed and altitude, but I didn't really have any trouble controlling lateral position. The cues seemed adequate for doing the task. The primary cue that seems to be lacking in this case is altitude, so I found myself actually using the radar altitude on the instrument panel to make corrections. HQR scale: Is it controllable? Yes. Is adequate performance attainable with tolerable workload? Yes. Is it satisfactory without improvement? I'd say no, because

of the altitude problem. I really should be able to perceive vertical rate without looking at the radar altimeter. Other than that, it was actually reasonably controllable so I would say minor but annoying deficiencies. Desired performance requires moderate compensation which makes it an HQR 4.

Run 305 (Bobup/Down). On that the vertical rate cues are pretty much missing, especially coming down. I also think the lack of motion really is a major defect area. You can't feel collective input, so the combination of the lack of vertical rate cues plus the lack of heave cues in the motion makes it easy to overshoot. There's a lot of collective reversals that are not typical height control tasks in a helicopter. It makes it appear like the heave damping is low. With that in mind, the HQR: Is it controllable? Yes. Adequate compensation with a tolerable workload? Yes. Satisfactory without improvement? No. There are moderately objectionable deficiencies in that, in spite of the fact that the performance was desired. I think the workload definitely required considerable compensation. I think the deficiency is definitely one that's moderately objectionable so I'm going to make this decision that you have to make on Cooper-Harper, and go to the next higher rating to report on the workload rather than the performance so the HQR is 5.

Run 306 (Dash/Quickstop). Primary thing to note there for me is, on the quickstop it was very difficult to perceive the closure rate with the target at the end point. It's a tendency that you think everything is fine, and not pitch up too much. You go up 10 degrees, and towards the very end you realize that it's really closing much quicker. That forces the 15 to 20 degree pitchup in the end, and that results in the loss of the forward field. I think that wouldn't occur if we had better X dot cues, horizontal translation cues. Pilot rating: Is it controllable? Yes. Adequate performance attainable with a tolerable workload? Yes. Satisfactory without improvement? No. I believe the lack of X dot cues coupled with the loss of the field of view when you pitch up like that results in somewhere between a 4 and a 5. It's not quite as bad as being moderately objectionable because it goes pretty good until the very end. I'd say an HQR 5. It's moderately objectionable because of that lack of authority to perceive the closure rate.

Run 307 (Sidestep). One thing that became noticeable, in truth throughout all the maneuvers, is that it's difficult to sort out the difference between pitching down and going backwards. I notice that especially here. It's also very much true in the pirouette. It's difficult to tell if I'm drifting back or it's a pitchdown, and I think that results in the uncertainties, and where you are in X, therefore it's difficult to tell how to control it. As far as the sidestep goes, other than the X problem, the problem is mainly at the ends where you make the transition, there's a little bobbling in attitude and so on. Of all the maneuvers I've done, that one seemed to go about the best. Is it controllable? Yes. Adequate performance with a tolerable workload? Yes. Is it satisfactory without improvement? Not really, because of all the bobbling at each end and the transition points. There is also a lot of roll, pitch, heave activity. It wasn't a nice crisp stop, do the maneuver, and then go the other way. I was able to stay within desired performance. Again, it's one of these cases where performance is desired, but the workload is high. The continual bobbling around doesn't affect desired performance so in this case we'll go HQR 4-1/2. It's between minor but annoying and moderate deficiencies.

Baseline Configuration (Fixed Base)

Run 308 (Hover). It's pretty much characterized by a low frequency wandering. Most of the time the cone was in the window except that it was continuously wandering around. It seemed like in spite of my best efforts, it was very difficult to stop it. The only trick you can play is to try to cheat the simulator, and back off it, and just hope that it will stay there. I did that once, and it drifted. Once I got back in that loop, it started that continuous motion. Any attempt at closed-loop control

and precise positioning of that cone just results in this continuous drifting, and the requirement to get out of the loop. With that in mind, is it controllable? Yes. Is adequate performance attainable with a tolerable workload? Yes. Is it satisfactory without improvement? No. That's because of the drifting. It's moderately objectionable. Any attempt to make it better actually makes it worse, which is objectionable. The HQR is 5.

Run 309 (Vertical Translation). That was interesting. It seems to have a little better control for some reason, especially down to 10 feet, where you're actually able to keep the cone reasonably stable. During the climbing part, the cone kind of got away from me, and we got into that old low frequency drifting. It seemed like, if I tightened up, I did have a little better control. I just had that perception that time, although the characterization was kind of the same as the hover, that there was not that positive control over X and Y you like to have in a hover. That's primarily due to the inability to pick up the very small rates which might become large rates. Is it controllable? Yes. Is adequate performance attainable with a tolerable workload? Yes. Is it satisfactory without improvement? No. Because I was able to keep the cone somewhat stabilized, I think we'll classify that as a minor but annoying deficiency, somewhere between that and moderately objectionable, HQR 4-1/2.

Configuration E (Fixed Base)

Run 310 (Hover). The most noticeable thing here, this is the third configuration I've flown, is that it's extremely difficult to tell one configuration from the other. If you were to tell me they're all the same I would believe it. I'm looking for differences so I might have perceived a slight tendency for it to be a little looser in roll A few times I got into a roll oscillation. Just as soon as I figured I had it identified, something different in the shortcoming or deficiency, I'd get out of that oscillation, and the cone would stay reasonably still for a while, then I'd back in to it again. It's very much cyclic of stabilize, get off, try to control it, slosh around, get back stabilized again, and that seems to be true of all of these. There's nothing remarkable about this one; it seems similar to the others with a possible exception that it seems slightly looser, and more sluggish and less crisp and predictable in roll. Is it controllable? Yes. Is adequate performance attainable with a tolerable pilot workload? Yes. Is it satisfactory without improvement? No. It's that lack of crispness in roll, and tendency for low frequency wandering. The HQR is a 5.

Run 311 (Vertical Translation). I noticed looking inside, I'd get into some of these oscillations that I referred to. The pitch attitude changed as much as plus or minus 2 degrees, and sometimes plus or minus 3 or 4 degrees in roll. This is a lot for a precision hover type task. You get behind it, and get in these large attitudes which result from the large translation that builds up unnoticeably, and that requires large attitude, and that gets the whole action going. Okay, is it controllable? Yes. Is adequate performance attained with a tolerable pilot workload? Yes. Is it satisfactory without improvement? No. It's a moderately objectionable deficiency. Actually, in this case between moderately and very objectionable because of those periods of significant oscillations. HQR 5-1/2.

Configuration G (Fixed Base)

Run 312 (Hover). That one, finally I saw some significant difference there. It seems to be very sluggish and unpredictable. I felt somewhat detached from it, and always very behind it. One or two times I saw attitudes when I got behind it as much as 5 degrees away from hover trim trying to recover. It's certainly sluggish, and a strong feeling of being detached. Primary comments: Is it controllable? Yes. Is adequate performance attainable with a tolerable pilot workload? No. Not

in this case. In fact, let me stop and review that. Hover, adequate is to keep the cone within the window at least 50% of the time, altitude plus or minus 5 feet heading within 10 degrees. I believe my heading was probably off more than that. There was never time to look at heading. I think I saw my altitude at least close to 5 feet off. The cone may have been in the window close to 50% of the time. A few times it got totally out of the window, and it's always on its way out. The workload was definitely in the category of major deficiency. That's the real driver here. To get me down here the workload is not tolerable even though the performance may have been adequate. The second half of the question is, with a tolerable workload — that part's no. Let's call that between a 7 and an 8. Adequate performance not attainable with maximum tolerable compensation. Controllability not in question, is probably the right answer. HQR 7.

Run 313 (Vertical Translation). The landing task with that same configuration just exposed the problem even more. It's one of those configurations where you just don't tease it, you've got to keep everything very small and very gentle. It all seemed to be going very well during the descent, and during the ascent back up to 30 feet I got in to it a little bit, and started to get in the loop, and wound up with some very large pitch and roll attitudes, and very large XY excursions. Bordering on, I actually lost control. Okay, is it controllable? Yes. Adequate performance with a tolerable pilot workload? No. The workload isn't tolerable. I don't believe the performance, strictly speaking, was even adequate. Let's see, vertical landing, keeping the cone in the right window 50%, the heading plus or minus ten. No, I don't think it's even adequate. Now, also plus or minus two in altitude? That's right, so major deficiencies, HQR 7-1/2. I think even control was becoming an issue on this one. I just wouldn't want to be in a real helicopter with that going on.

Configuration D (Fixed Base)

Run 314 (Hover and Vertical Translation). We combined the hover with the vertical translation because we're running out of time here. That configuration was a lot more predictable both in pitch and roll. I felt like I had good control over the attitude of the aircraft, but my visual cueing, I still couldn't perceive the rate. I'd get into these low frequency oscillations. It was still the same symptom but much less with this. I was actually able to keep the cones in the window even though it wandered about quite a bit. The peak attitude excursions were down in the order of one or two degrees, as opposed to five degrees. It's been like that so the primary symptoms are low frequency wandering of position. Cooper-Harper for the hover: Is it controllable? Yes. Is adequate performance attainable with tolerable pilot workload? Yes. Satisfactory without improvement? No. In that case, the hover actually went reasonably well. A few times it started to slide around so it's between minor but annoying and moderately objectionable, HQR 4-1/2.

The landing task was not as controllable. The problem in landing is it's a divided attention task, and when I got into the heave axis then the X and Y started to get away, so the division of attention exposes this low frequency XY problem for me quite a bit. So the HQR for the vertical landing: Is it controllable? Yes. Is adequate performance attainable with tolerable workload? Yes. Satisfactory without improvement? No. In this case it's between moderately and very objectionable, HQR 5-1/2.

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An exploratory simulation was conducted on the NASA Ames Research Center's Vertical Motion Simulator (VMS) to evaluate the effects of simulator characteristics on handling qualities for performing hover and low-speed tasks in a helicopter. The primary focus of the study was on subjective assessments of the variations, based on Cooper-Harper Handling Qualities Ratings (HQR's), rather than objective measures of pilot performance. Effects of variations in the three major elements of the simulation--the motion system, visual system, and math model--were evaluated. Seven precision and aggressive low-speed Mission-Task-Elements were performed. All tasks were Level 2 (average HQR worse than 3.5) fixed-base for the baseline helicopter, which was designed to provide Level 1 handling qualities in the real world. Addition of motion improved ratings 1/2 to 2 points, resulting in Level 1 handling qualities for most tasks. Tradeoffs in motion acceleration gain and washout break frequency were evaluated with two sets of motion washouts. There was a preference for reduced washout frequencies (resulting in improved phasing between the visual and motion responses at mid

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to high frequencies, at the sacrifice of onset gain) for the precision tasks. Conversely, there was a slight preference for increased onset gains (at the sacrifice of visual/motion phasing) for the aggressive tasks. The effects on handling qualities of a visual delay compensation algorithm were investigated by three pilots. With the algorithm active, visual pipeline delays are effectively removed, resulting in a mismatch between the visual and motion responses. Pilot opinion was mixed on the value of this algorithm, with two pilots preferring it off and one preferring it on. The effect of visual delay on handling qualities was generally less than the effect of an equivalent overall transport delay. The results of this simulation are compared with several existing and proposed criteria for judging simulation motion fidelity, and recommendations are made for a more formal simulation program.